SELECTION OF MOTOR EQUIPMENT

FOR THE

ELECTRIFICATION OF THE C. R. I. & P. RY.

BY

F. C. COLLINS and S. A. SOUTHER

Armour Institute of Technology

1908

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Selection of Motor Equipment
for the Electrification of

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SELECTION OF MOTOR EQUIPMENT

FOR THE

ELECTRIFICATION OF THE C. R. I. & P. Ry.

DESIGN OF BLUE ISLAND POWER PLANT

A THESIS

PRESENTED BY

F. C. COLLINS S. A. SOUTHER

TO THE

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OF

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BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

1908

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PART ONE.

SELECTION OF SCHEDULE SPEED, ACCELERATING RATE, PERCENT COASTING, AND MOTOR EQUIPMENT FOR THE CHICAGO, ROCK ISLAND And PACIFIC RAILWAY

PART ONE.

SELECTION OF SCENERY SUNED. ACCELERATING RATE.

PRESENT CHARTING. ADD LOCOS ELSEWHERE FOR TIME

CHICAGO, ROCK ISLAND
AND
PACIFIC RAILWAY

GENERAL STATEMENT OF PROBLEM.

The problem under consideration is the electrification of the Chicago terminal of the Chicago, Rock Island and Pacific Railway. "The chicago terminal" includes that part of the road lying between Blue Island and Chicago. The change is to apply to both the suburban and the through traffic but not to the freight service. The general track layout is indicated on the accompanying diagram, which shows a branch line leaving the main line at Gresham and returning to the same at Blue Island. Practically all the suburban service is handled via the branch line and all the through service over the main line. Over 125 trains are handled daily on this division. The project calls for the electrification of both branch and main lines.

REASONS FOR CHANGE OF MOTIVE POWER.

That the time is quickly approaching when the Chicago terminals of the several railways will have to be electrified will be admitted by even the railway officials. The difference in opinion is as to how

soon this time will arrive. It is not the intention to discuss that point here, the authors simply stating their conclusion that the time for such a change has arrived in the case of this road, and at least two others. This statement is backed-up by the fact that for some time past the Rock Island has gained the reputation of not being able to live up to its schedule. Much of this difficulty is due to congestion at the La Salle St. terminal. Another point that is causing considerable agitation for electric service is the smoke nuisance. Although this last point may eventually prove to be the deciding one, it is not given much weight in this report, the main reason for the change being as stated above, namely: An increase in terminal station and track capacity.

If the above were the only benifit to be obtained by such a change, it is douttfuliif the change would ever be made, because the investment involved is enormous. Of course, a certain part of the investment could be charged up against maintenance, renewals, or similar items; but, by far the larger amount would

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putation of not being able to live up to its opening.
Much of this difficulty is due to carelessness at its
le fault it. Certainly, Another point that is deserving
considerable attention for therein merits is the sub-
mechanism. Although this last point may eventual-
ly prove to be the deciding one, it is not first
many weighs in this respect, the main reason for the
chosen being no second storey usually: an increase in
terminal stocks and trade popularity.

If the above were the only benefit it obtained
by means a change, it is doubtful the change would
ever be made, because its investment deferred is ac-
curate. Of course, a certain part of the investment
could be charged as another extraordinary. Research, or
similar items; but, by far the largest element would

necessarily be considered as an investment and would, therefore, demand the return of a regular rate of interest. The sources of returns on the investment are found in the possible increase in traffic due to increased terminal and track capacity, and also in the much lower maintenance and operating expenses. That the last named item is not theoretical, but a substantial fact, larger than would be expected, may be seen by reference to the first annual report of the New York Central on the operation of the electrified zone. The results to be obtained by the change in motive power are stated below in the order of their importance.

1. Increase in track and terminal capacities.
2. Reduction in operating expenses.
3. Reduction in maintenance charges.
4. Increase in traffic.
5. Compliance with possible future city ordinances

INTRODUCTION.

The original scope of this investigation has been greatly reduced, because of lack of time to pro-

perly carry out all of the work. Great care has been given to the work inso far as it has progressed, all calculations having been carefully checked. The method used is described quite fully, and was developed entirely by the authors. It may appear to be somewhat cumbersome, but it must be remembered that not a single factor is held constant. If some of the factors were assumed or considered fixed the method becomes greatly simplified. Moreover, when looking over the methods advocated by the different authorities on the subject it was found that such methods would not apply to the case under consideration, as in every case the authorities referred to make assumptions which sacrafice accuracy for simplicity to too great an extent. Especially is this true when considering the higher speeds, where, although the error is small in amount it forms a large percentage of the total.

The factors that are considered as variables in the following investigation are: Schedule speed, accelerating rate, percent coasting, and the size of the motor equipment. The data was worked up for three

accelerating rates and three coasting values, in order to furnish sufficient data from which to construct curves. The line voltage was considered to be held approximately constant at 1200 volts, the intention being to determine the line drop from the typical calculations and to use the corrected line voltage when drawing up the final load curve.

GENERAL OUTLINE OF INVESTIGATION.

The following outline indicates the order in which the various factors were considered.

1. Selection of system.and sys
   - (a) 1200 volt, D.C.
   - (b) 3rd. rail.
   - (c) Multiple unit control
   - (d) Motor car - trailer operation.
2. Preliminary determinations.
   - (a) The typical run.
   - (b) The typical train.
   - (c) Train Resistance.
   - (d) Length of stops.
   - (e) Number of motors

3. Method of obtaining speed time curves.

(a) Derivation of typical characteristics.

(b) Derivation of speed-tractive effort equation.

(c) Determination of specific motor characteristics.

(d) Determination of speed-time curves.

4. Data from curves.

(a) Schedule speed.

(b) Power consumption.

(c) R.M.S. Current.

5. Conclusions.

(a) Variation of determining factors.

(b) Selection of schedule speed.

(c) Selection of accelerating rate.

(d) Selection of percent coasting.

(e) Selection of motor equipment.

SELECTION OF SYSTEM AND EQUIPMENT.

There are a great number of systems available, many of which may, however, be rejected simply on the basis of good judgement. In selecting a system for

this service a lengthy investigation of all possible systems was made, but is not included in this report because of its length, the results of the investigation being what are desired. The systems considered are enumerated below.

1. Direct current systems.
    (a) Gasoline - Electric.
    (b) Storage battery.
    (c) 600 volt :- 3rd rail or trolley.
    (d) 1200 volt:- 3rd rail or trolley.
2. Alternating current systems.
    (a) Poly-phase systems.
    (b) Single-phase

There are many features that tend to eliminate the gasoline- electric system. The maintenance charges are high, and even authorities favorable to this system agree that when the frequency of service is such as to necessitate over 500 car miles per day the trolley or third rail system should be used.

The storage battery system hardly calls for any remarks its past history being sufficient to deter

any conservative railroad man from considering it. its inadaptability for this service is so apparent that specific reasons are not necessary.

The poly-phase system is also easily eliminated, since it is not in use in this country at present, with possibly one exception, and standard lines of apparatus have not been developed by the manufacturing companies. This system has gained a foot hold in Europe because of the extreme grades encountered, in which case it has some great advantages. What is here considered an important disadvantage of the system is the necessity for more than one trolley wire. Other considerations tend to eliminate this system, but good judgement is probably the principal factor in dictating the use of some other system.

It was found, however, quite difficult to decide between the single-phase and the direct current systems. The reasoning involved in the decision between the systems is too lengthy to be included here. The principal objection to the single-phase system are its undesirable operating features in a service

involving frequent and numerous stops. It may also be pointed out that the decision in this case is largely dependent upon the engineer's inclinations, this fact being well illustrated by two recent installations which were both made by prominent engineers.

A direct current system having been selected it stil remains to choose between the 600 or 1200 volt system. The tendency is toward the higher voltage, and the latter was the one selected because it carries with it many advantages and few disadvantages, and has already been demonstrated to be entirely practicable. The development of the interpole motor has placed this system on an even basis with the standard 600 volt system. It was decided to use 600 volt interpole motors operating in series.

The trolley system was quickly discarded and the third rail decided upon. The third rail is to be mounted in a manner similar to that of the New York Central type but the rail section is different. The section adopted is of the U shaped type, it being the intention to place copper feeders in the third

rail and dispense with all other feeders if possible. This was also one reason for the selection of the 1200 volt system.

Train units composed of motor cars and trailers were selected after due consideration of the alternative system, namely, all motor car operation. It is evident that the adoption of the all motor car system would facilitate the making up of trains and tend to reduce congestion in the yards. Such a combination also tends to increase the reliability of service. The most important factor here involved, however, is the matter of maintenance, since it is cheaper to keep in repair a small number of large motors than a large number of small ones. This being a running expense it is an very important consideration. Another point involved, although slightly foreign to the indicated purpose of this paper, is the matter of the first cost of eqipment. Their are at present in use on this railroad a large number of good suburban coaches that would require but slight changes to make them adaptable for use as trailers.

Therefore, it is evident that combined motor car and trailer operation is to be desired if same can be accomplished without too great a sacrafice of the other factors previously stated. By the adoption of a judicious system of making up trains same may be handled in terminals, such as the LaSalle St. station, with as much ease as is possible with the all-motor car system. The factor of terminal station and terminal track capacity is of first importance and the principal elements of operation necessary to produce the desired results are: A high accelerating rate and the ability to operate the train from either end. Both of these requirements may be met with the combined motor-car trailer system, and therefore the logical selection of the above system follows.

Multiple unit control is adopted in order to facilitate the operation of the train unit, especially at terminals and in the yards. The trailers may readily be wired so as to make the train line of the control system continuous from end to end.

PRELIMINARY DETERMINATIONS.

The following calculations are all based on a so called typical run. This typical run was obtained from a study of the profile and alignment of the road and represents average conditions. The assumption of a straight and level run is justified because the existing grades are very small and all curves, calling for a reduction in speed, are located at stations. All signal stops were here considered as fixed stops in order to give the condition of maximum demand on the equipment.

In order to reduce the amount of work as far as possible, it was decided to determine the combination of motor cars and trailers which would impose the maximum requirement on the system and equipment, and base all calculations on this "typical train". After reviewing the present train make-up, it was decided that the typical train for electric service would be a four car train. All the considerations leading to such a decision can not be stated but one

PRELIMINARY DETERMINATIONS.

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ation of water gage and tractive effort would induced

the maximum requirement on the motors and equipment.

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mention to what a decision can not be stated for one

conclusive statement may be made, namely: The decis- has been made in favor of a motor car-trailer train unit. If a three car train were adopted as the typical train, very little figuring would be required to show that it would be practically impossible to operate under ordinary conditions one motor car and two trailers. Furthermore, a little figuring would indicate that the difference in maintenance with two-thirds of the cars motor cars and with all cars motor cars, would hardly counterbalance the greater convenience of the all-motor car system. It is possible, however, to operate a four car train with a combination of two motor cars and two trailers, and therefore the four car train was selected as the typical train.

Although the factor known as train resistance can not be very accurately determined, such an equation may be selected as a basis as will give quite satisfactory results. Much of the inaccuracy encountered through this factor is due to lack of care, when deciding upon an equation, to select such an equation and constants as will apply to the class of

service under consideration. There are any number of such equations which have the same general form, but involve different constants, these constants depending upon the kind and class of service, the type and condition of equipment, road bed etc. The equation finally adopted for this class of service was the revised Armstrong formula.

When calculating the schedule speed it is necessary to consider the time required for stops. In order to have some basis upon which to assume the time of stops note was taken of the time required at present. Theresults obtainedwere surprising. In all cases the stops were exceedingly long, being as high as thirty five seconds in many instances and averaged approximately thirty seconds. It was decided, by observing the actions of the passengers when leaving the train, that such lengthy stops are not necessary and are merely theresult of a habit of the passengers of remaining in their seats until the train comes to a dead stop. It was therefore decided that by training the passengers and giving special attention

service under consideration. There are any number of such equations which have the same general form, but involve different constants, these constants depending upon the kind and class of service, the type and condition of equipment, road bed etc. The equation finally adopted for this class of service was the revised Armstrong formula.

When calculating the adiabatic grade it is necessary to consider the time required for stops. In order to have some basis upon which to measure the time of stops made the times of the time required at present. Theoretic observations concluded. In all cases the stops were successful ones, since as will be fully [illegible] in later [illegible] examined critically after records. It was decided, by observing the actions of the [illegible] the train the train, that most locomotive drivers not necessary and are partly [illegible] of a habit of the [illegible] of [illegible] in their early until the train comes to a dead stop. It was therefore decided that in [illegible] the [illegible] and write [illegible] attention

to this matter, the average length of stop could easily be reduced to twenty seconds, hence that value has been used throughout the calculations.

The decision has now been carried down to the point of a four car train, composed of two motor cars and two trailers. The tendency is to use a small number of large motors because of the lower cost of inspection and repairs. The decision for a two or four motor equipment is definately fixed by the consideration of the weight available for traction. It became evident early in the work that the total weight of the car would be required for this purpose, thereby necessitating the use of all four axles as driving axles. The same decision may also be reached from another view point, which point did not become evident until a later stage of the work. The results show that a motor having a commercial rating of approximately 150 H.P. is required with a four motor equipment. If a two motor equipment had been used this would necessitate the use of a 300 H.P. motor. The largest motor yet used in such service is rated at 200

horse power. Mechanical considerations would also prevent the use of a motor of that size under a car. The above facts show the necessity of using four motors per car, regardless of the advantages of the two motor equipment in the matter of first cost, lower maintenance and inspection charges, etc.

METHOD OF OBTAINING SPEED-TIME CURVES.

After studying the various methods previously used attacking this problem, it was decided that the best method would be to ignore all such methods and develop one for the case in hand, making such assumptions as are allowable and obtaining such accuracy as is consistent with unavoidable sources of error. In attempting to obtain characteristics of inter-pole motors, some difficulty was experienced due to the fact that in every case the motor was designed for high speed rather than for short -run-low speed work. As a preliminary, a study was made of the shapes of different motor characteristics, their variations, and the causes for same; it was found that the variation

in shape was very small for wide ranges in horse power when compared on the basis of percent load. There was, however, considerable variation in the position of the curves with respect to the axis. That is, if the efficiency curve was produced until it intersected the axis, an entirely theoretical point, it will be found that the current value at the point of intersection is higher in one case than in another, and also that one efficiency curve rises to a higher value than the other (considering motors of the same size) and moreover, that the curve that intersects the axis at the highest current value has the highest maximum efficiency. Now, this variation is easily adjusted by properly proportioning the core and copper losses. If, as is the case on this project, the motor is to operate at high current values for a large part of the time, it is evident that the losses should be so proportioned as to give a low copper loss and the correspondingly higher core loss. It is also true that by altering the armature specifications the point of

maximum efficiency may be shifted over a fairly large range. The above statements will serve to indicate the line of reasoning used to derive a typical efficiency curve. " Typical" in this case, does not imply a curve that will apply to all railway motors but is limited to a certain range and class of service. For example: In this work such a derived efficiency curve was used for motors ranging in size from 75 H.P. to 125 H.P. and a second curve was derived for motors ranging from 125 to 175 H.P. It was found by observation that the error introduced by such a method is much smaller than those introduced through the inaccuracy of the characteristics supplied by the manufacturer.

The basis of the following method of procedure is the derivation of a set of typical motor characteristics which may be used for the calculation of the speed-time curves, for motors of various sizes. A set of motor characteristics, for a motor of approximately the same size as it is considered will be required, were selected and the shape of the efficiency

curve altered so as to best suit the service, the corresponding necessary changes being made in the other characteristics.

Having obtained the characteristics, the next step was to derive an equation showing the relation between speed, tractive effort, and output. The derivation of such an equation is readily accomplished and is based on the simple equation for motor torque,

$$T' = 7.04\ P/S.$$

where P is the motor output in watts and S is the armature speed in R.P.M. The final equation follows:

$$T = .502\frac{E\ I\ \emptyset}{V\quad V}$$

where T equals the tractive effort in pounds

E equals the motor voltage.

I equals the current input.

$\emptyset$ equals the percent efficiency.

V equals the speed in Mi. per Hr.

A reasonable starting current was then assumed, e.g., about 130 percent of normal full-load current and the proper efficiency taken from the curve.

curve altered so as to best suit the service. The

corresponding necessary changes being made in the

other characteristics.

Having obtained the characteristics, the next step

was to derive an equation showing the relation be-

tween speed, effective field output. The analy-

sis at hand is somewhat complicated

and is based on the following symbols for motor torque.

$$T = T_1 (\Phi_1 \Phi_2 \sin \theta).$$

where T is the motor torque in watts and θ is the

armature speed in R.P.M. The final equation follows:

$$T = \frac{\text{[illegible]}}{\text{[illegible]}}$$

where * equals the charging effort in [illegible]

T equals the motor efficie[illegible]

I equals the current [illegible]

R equals the reversal efficiency.

V equals the speed in M. per Sec.

A resembles electric current and then assumes.

e.g. about 150 [illegible] at voltage [illegible] current

and the [illegible] efficiency [illegible] the motor.

The acceleration was then decided upon and the tractive effort required for the same determined from the equation

$$\alpha = (T - H) / 100 \text{ Wt.}$$

An allowance of 10 percent is made in the above equation for the inertia of rotating parts. In the equation Wt. is the weight of the car expressed in tons per motor, all calculations being based upon the motor as a unit. H is the train resistance in pounds . From this equation, may be calculated the net tractive effort required for acceleration. Returning to the tractive effort equation, E, I, and ϕ are known and, as a first approximation, T - H is considered equal to T. V may then be solved for, the result being an approximate value. This value of V is slightly high, e.g., if the true value of V is 20 m.p.h., V will solve out equal to 21, due to the neglect of train resistance. Then, knowing that the true V will be slightly lower than that found by the approximation, the value of the train resistance is determined for

The acceleration was then decided upon and the tractive effort required for the case determined from the equation

$$= T - R \setminus 100 \text{ We.}$$

An allowance of 10 percent is made in the above equation for the inertia of rotating parts. In the equation T, is the weight of the car or-trains it tons per motor, all calculations being based upon the motor as a unit, E is the train resistance in pounds . From this equation, may be calculated the net tractive effort required for acceleration. Returning to the tractive effort equation, E, i, and f are given and. as a first approximation, T - E is calculated equal to I. V may then be solved for, the result being an approximate value. This value of V is slightly high. e.g., if the true value of V be 20 m.p.h., V will solve out equal to 30, due to the reactance of track resistance. Then, knowing that the true time V will be slightly lower than that found by the alternation, the value of the train resistance is determined for

a velocity slightly lower than the approximate V. This value of H is then added to the value T - H which was calculated above, giving the total tractive effort developed, or T. This value is then substituted in the tractive effort equation and the true V obtained. This value of V corresponds to the speed of the train at the instant that all rheostat resistance is cut out of circuit and operation is commencing on the motor curve.

We now have a value of T and a value of V corresponding to a given current value This current value (Or percent load.) is located on the "typical" characteristic curve sheet and the values of the ordinates of the tractive effort and speed curves. It will be noted that there are no vertical scales on this curve sheet and the values are simply specified in terms of the smallest division as a unit. Then, having the value of the tractive effort at that point in both pounds and coordinate divisions the value of one division, in pounds tractive effort, may be determined by dividing

a velocity slightly lower than the anticipated V. This value of N is then added to the value I - X which was calculated before, giving the total inductive effort involved, or Y. This value is then substituted in the inductive effort equation and the true V obtained. This value of V corresponds to the speed of the train at the instant that all flywheel resistance is cut out of circuit and operation is commenced on the motor curve.

To any rate a point at I and a value of V corresponding to a given governor value (the current value (or current load.) is located on the "typical" characteristic curve sheet and the values of the ordinates of the inductive effort and speed curves. It will be noted that these are so vertical angles or this curve sheet and the values are simply plotted in terms of the electrical horsepower at a unit. That, having the value of the inductive effort at that point in both curves a point coordinate identifies the value of one division. In similar inductive effort, may be determined by determin-

the numerical value of the tractive effort by the corresponding number of divisions. For example: If the value of the tractive effort, as determined by the above method, was found to be 2000 pounds at 100% load, the percent load is located on the horizontal scale of the typical curve sheet and the value of the ordinate to the tractive effort curve, at that point is found to be 100 divisions on the coordinate paper, the value of one division is then equal to 20 pounds. In exactly the same way the value of one division on the speed ordinates may be determined.

Temporary current values may then be substituted on the typical curve sheet for percent load. Then a small table is drawn up having several columns, one for current values in amperes, one for the corresponding tractive effort values in coordinate divisions, and one for the corresponding speed values. Then at certain current intervals, say, every 20 amperes, the number of divisions in the ordinates to the curves are noted and recorded in the above tabular form.

the numerical value of the tractive effort by the corresponding number of divisions. For example: If the value of the tractive effort, as determined by the above method, was found to be 8000 pounds at 100% load, the moment load is located on the horizontal scale of the typical curve sheet and the value of the ordinate to the tractive effort curve, at that point is found to be 125 divisions on the coordinate paper. The value of one division is then equal to 80 pounds. In exactly the same way the value of one division on the speed ordinates may be determined.

Tentative average values may then be checked on the typical curve sheet for percent load. Then a small table is drawn up having several columns. One for current values in amperes, one for the corresponding tractive effort values in pounds divisions, and one for the corresponding speed values. Then at certain current intervals, say, every 50 amperes, the number of divisions in the vertical to the curves are noted and recorded in the three respective columns.

The proper scales are then laid off on coordinate paper, abscissas in amperes, and ordinates in pounds tractive effort and speed in m.p.h.. Then, a few manipulations of the slide rule will rapidly determine the speed and tractive effort values corresponding to the several current values, which values are then plotted. This proceedure results in the determination of speed and tractive effort characteristics for a certain motor, for a given starting current, and for a given acceleration. It will be noted that up to this point no reference has been made to gear ratio and apparently all calculations are made independently of same. The manner in which gear ratio enters into the determination is indicated below. Since the principal change produced by the variation of the gear ratio, all other factors remaining the same, is to produce a change in acceleration, the effect of changing the accelerating rate is essentially specifying a change in gear ratio, although the actual ratio is not known. The characteristics for other accelerating rates, are readily determined in the same manner as

indicated above, it being possible to use much of the previously determined data in the subsequent calculations. (For the same motor.)

In this project, characteristics for three accelerating rates, involving practically three different gear ratios, were calculated for each motor. The characteristics for several motors of different capacities were calculated in the same way. It may be well to note at this point the method of distinguishing between motors. When considering another motor, the only difference apparent in the preliminary data, is the change in the value of the starting current. This method of rating a motor may seem in error from the stand-point of heating but is entirely allowable when used for the calculation of speed -time curves. By this method, two starting currents may be considered as specifying two motors of different ratings on the same percent overload. All of the motor characteristics shown in this report were obtained by the above method.

Having obtained the motor characteristics, it is

a comparatively simple matter to derive the speed-time curves. The calculations involved in plotting the various speed-time curves are omitted from this report. The method of obtaining the remaining points on the speed-time curves is that ordinarily employed and involves no special features, being essentially that outlined in the articles by Mr.E.F.Wynne, on Electric Railway Engineering, Vol.3 of the Electric Journal.

The speed-time curves for all motors were plotted using various percentages of coasting, the values chosen being, 0%, 25%, and 40%. A constant braking rate of 1.5 mi. per Hr. per Sec. was considered to be the best value and was used for all curves. In applying these values to the curves the coasting and braking lines, drawn at the proper slope, were shifted until the curve was found to enclosedthe area necessary to represent the complete run, the coasting always being maintained at the proper percentage of the total time. Sinceall coasting values were used with each of the three accelerating rates, 1.1, 1.4, and 1.7 Mi. per Hr. per Sec., the resultant number of

curves for each motor was eighteen, nine of which were current curves.

DATA FROM CURVES.

Having determined the speed-time and current curves the next step is to draw from same certain data and facts. Such data is included in tabular form on each curve sheet. From the speed-time curves the schedule speeds obtainable are readily calculated. From the current curves it is possible to determine the power required to make the run, which is then expressed in terms of watt Hrs. per ton mile. Up to this time the equipment has not been considered from the stand point of heating . It was originally intended to consider this phase of the subject very fully, but the time available did not permit. The tendency in this work has been rather to decide what motor characteristics are required in order to give the best service and then to require the manufacturer to build such a motor, having the operating characteristics specified. Such a method is entirely justifiable if good judgement is used and the characteristics demanded are consistent

with the commercial features involved. It was for this reason than unusual care was exercised in obtaining the typical characteristics and selecting starting currents. The $\sqrt{\text{mean } I^2}$ was calculated. however, for eah each motor. each accelerating rate, and each percent of coasting. These values do not give any information as to the actual heating of the motor but are useful in determining the relative heating.

CONCLUSIONS.

From the data obtained from these curves the following sets of curves were plotted for all the motors, on the same curve sheet.

1. Schedule speed and power consumption.
   Constant acceleration, variable % coasting, and constant KW. per ton.

2. Schedule speed and power consumption.
   Variable acceleration, constant % coasting, and constant KW. per ton.

3. Schedule speed and power consumption.
   Constant acceleration, constant % coasting, and variable KW. per ton.

4. Schedule speed and $\sqrt{\text{Mean } I^2}$.
   Constant acceleration and constant KW. per ton.

with the commercial features involved. It was for this
reason that manual work was supplemented by obtaining
the typical characteristics and volumetric quantities
concrete. The mean I was calculated. However, for a
real motor, deep consideration must be used because
of monetize. Those values to use via interpo-
ation is to the second reading, or the later but one
method is determine the relative benefits.

Conclusion.

From the data supplied from these curves the
following sets of curves were plotted for all the
motors. It the most clear cut.

1. Relative speed and power consumption.
Constant horsepower. Variable I resistance.
Not obtainable CT. not too.

2. Relative speed and power consumption.
Variable horsepower, resistance I variable.
not obtainable TT. yes too.

3. Relative speed and power consumption.
Constant horsepower. resistance I variable.
not available IT. not too.

4. Relative speed and Power I .
Constant horsepower and resistor IT. not
too.

TT.

These curves show the best operating points for each motor. It is apparent, that since there are several variable factors to be considered, all of which affect each other, it is necessary to consider them collectively. Hence the necessity for curves showing the simultaneous variation of all variable factors. The method of plotting these curves is self-evident, all the necessary data being taken from table number 1. Sufficient data and curves are now at hand to draw the conclusions that prompted the investigation, namely: The determination of the schedule speed, accelerating rate, percent coasting, and size of motor that would result in such a service as would best accomplish the objects of electrification, previously stated.

The determinations, outlined above, are probably the most important part of the report. In making these determinations, it is essential that the objects of electrification, previously stated, be kept clearly in mind. These objects, together with the factors necessary for their attainment, are restated below.

1. INCREASE IN TRACK AND TERMINAL STATION CAPACITIES.

(a) High accelerating rate.

(b) High braking rate.

(c) Multiple unit system of control.

(d) High schedule speed.

2. REDUCTION OF OPERATING EXPENSES.

(a) High accelerating rate.

(b) High braking rate.

(c) Low schedule speed.

(d) Large amount of coasting.

3. REDUCTION OF MAINTENANCE EXPENSES.

(a) Minimum number of motors per car.

(b) Minimum number of motor cars.

(c) Moderate braking rate.

4. INCREASE IN TRAFFIC.

(a) Increased frequency of service.

(b) Decrease in rates.

(c) Increase in population due to improved service

(d) Reliable service.

5. COMPLIANCE WITH POSSIBLE FUTURE CITY ORDINANCES.

(a) Electrification of Chicago terminal.

1. INCREASE IN TRACK AND TECHNICAL STATIC CAPACITIES.

(a) Kilj Accelerating rate.

(b) Kilj Breaking rate.

(c) Modified best grade of section.

(d) Less restrictive speed.

2. REDUCTION IN OPERATING EXPENSES.

(a) Kilj Accelerating Tele.

(f) Kilj Trailing rate.

(c) Less effective speed.

(d) Terms adapted of practice.

3. REDUCTION OF MAINTENANCE EXPENSES.

(a) Kilj Cause of delay in use.

(c) Minimum number of motor cars.

(c) Moderate braking rate.

4. INCREASE IN TRAFFIC.

(a) Increased frequency of service.

(f) Reduced fe Tele.

(d) Increase in [illegible] due to improved service

(d) Reliable service.

5. CONSIDERATIONS WHICH INFLUENCE CITY DEVELOPMENT.

(a) Elevation of Climate [illegible].

DETERMINATION OF SCHEDULE SPEED.

It will be noted that the matter of schedule speed conflicts in several instances, increase in track and terminal capacity calling for a high schedule and a reduction in operating expenses calling for a low schedule. The lowest limit for the schedule speed may be set at that obtained, 21.7 m.p.h. Moreover, the factor of schedule speed is not of any great importance when considering terminal capacity. It is therefore considered advisable to give the matter of operating expenses greater weight and to adopt the most economical schedule speed. By " Economical schedule speed" is meant the speed at which the power consumption has a reasonable value, and above which, the power consumption increases at a greater rate than the speed. By a consideration of the curves on sheets 1 and 2, collectively, a general idea of the variation of power required with schedule speed, may be formed. These curves indicate that the best schedule lies between twenty-four and twenty-five miles per hour.

It will be noted that the matter of economic speed conflicts in several instances. Increase in track and terminal capacity calling for a high schedule and a reduction in economic cruising speed for a low schedule. The lower limit for the schedule speed was, in one at least instance, 12.7 m.p.h. However, the factor of schedule speed is not of any great importance when considering terminal capacity. It is therefore considered advisable to give the matter of operation greater weight and to adopt the more economical schedule speed. By "terminal capacity" is meant the speed at which the given operation can handle a reasonable volume and allow cars. The power requirements increase if a greater rate of acceleration is used. By a complete train of five cars is meant a motor car and four trailers, a general idea of the variation of power required will probably always be found. These curves indicate that the best schedule time between twenty-five and twenty-six miles per hour.

DETERMINATION OF THE REMAINING FACTORS.

The factors here refered to are: accelerating rate, percent coasting, and size of motor. It is readily apparent that these factors are so inter-connected that they must necessarily be selected simultaneously. All the possible combinations of these three factors are shown on the curve sheets and therefore the best possible combination is easily ascertained by inspection.

Reference to the curves shows that there are at least two combinations satisfactorily, as far as schedule speed and power consumption are concerned. These combinations are:

Motor No.5 -- acceleration = 1.7 - 25% coasting.

Motor No.5 -- Acceleration = 1.4 - 40% coasting.

The later combination was the one selected because of the moderate acceleration allowed, and also because of the larger amount of coasting obtainable. With the 1.7 combination, the difference in the time taken for the run, with 0% coasting and with 25% coasting is only three seconds and therefore does not leave much chance for making up time. With the 1.4 com-

DETERMINATION OF THE REMAINING FACTORS.

The factors here required in the second diffe-
rence column are of either 2 or 3. If a re-
markably flat curve is obtained, it is usually
safe to assume 2 as the factor. All
the remaining differences of this column are
given as the first differences of the next co-
lumn, thus completing the family according to
law.

Returning to the second differences, we
have for multiplying numbers 2, 3, 4, 5, 6,
and 7, the products 2, 6, 12, 20, 30, and 42.
Continuing we:

Enter 2.0 -- subtracting = 2.7 - 720 constant.

Enter 2.2 -- subtracting = 3.4 - 420 constant.

The later constants are the ones entered
at the moderate acceleration altered. And then by-
means of the latter number 21 constant obtained.
Till the 3.7 constant. The difference in the flow
rates for five, only 20 entries are then 201 inter-
val. In this manner accurate and flattened flow lift
curve for ratio. That the 1.2 rec-

bination the difference in the time required for the run, on 0% and 40% coasting, is about 7 seconds, which point greatly favors this system. Both combinations are operating at favorable points on their $\sqrt{\text{mean } I^2}$ current curves, the 1.7 combination being lower in value however, than the 1.4 The point representing the combination selected is indicated, on all the curve sheets, by a double circle.

The factors, schedule speed, accelerating rate, percent coasting, and size of motor, having been definately selected, the purpose of this investigation has been accomplished.

PART TWO.

DESIGN OF BLUE ISLAND POWER PLANT
for the
CHICAGO, ROCK ISLAND AND PACIFIC RAILWAY

DESIGN OF BLUE ISLAND POWER PLANT.

CHICAGO, ROCK ISLAND AND PACIFIC RAILWAY.

Power plant design involves various economic, as well as purely engineering considerations, each of which must be given due weight in order to approach ideal conditions. In railway work the question of reliability of service is of paramount importance; a close second is the matter of cost in connection with the generation and transmission of power. The item of cost largely determines the success of the project, since any steam road electrification is expected to show increased service economies over those obtained in the corresponding steam operation. These economies must at least balance the increased fixed charges, due to the electrical investment.

The minimum investment in generating station is not compatible with the requirement of reliability; in fact experience indicates the advisibility of taking every reasonable precaution to insure continuity of operation, regardless of the additional cost involved. These statements are made to justify points

DESIGN OF RULE ISLAND POWER PLANT.

CHICAGO, ROCK ISLAND AND PACIFIC RAILWAY.

Power plant design involves various economic, as well as purely engineering considerations, each of which must be given due weight in order to attain ideal conditions. In making use of the question of reliability of service in of primary importance; a close second to the matter of cost is conservation and transmission of power. The item of cost largely determines the economy of the project. Since any steps that eliminate or minimize to some important service economies even first cost entails in the commercially wise operation. Items economies must at later periods follow the increased fixed charges, due to the eliminated investment.

The studies summarized in subsequent sections do not completely with the development of details; in fact engineering judgment the selection of many practically possible quality of operation, magnification of the additional cost involved. Often questions are easy to justify purchase

in design, which may at first sight seem to involve greater expenditures than are absolutely necessary.

After the preliminary determination to consider only a steam turbine driven installation, the principal problem presented for solution was the selection of a site for the proposed station. The main factors governing such a proposition are the cost of land, the available supply of condensing water, and the facilities for fuel storage and transportation. It would have been desirable to locate approximately at the center of the load, but was deemed inadvisable, however, on account of the high price of land and the lack of sufficient water for condensing purposes. The use of high tension transmission of power, also in a larg measure reduces the necessity for a centrally located station. The site finally chosen fullfils admireably the conditions necessary for a satisfactory location. It is situated near the southern end of the Rock Island suburban division at Blue Island, Ill. and adjacent to the intersection of the Calumet River and the tracks of the Chicago Terminal Transfer Rail-

way. It is several hundred feet north of the present generating station of the North Shore Electric Co., and about one-half mile east of the Rock Island main line.

In the preliminary design, it was determined to so proportion the plant, as to provide a liberal amount of room for the generating and auxillary apparatus. This is entirely allowable, since the cost of land is relatively low, and literality in this respect facilitates operating and results in decreased costs for repairs. It is also a simpler matter to keep the station clean, which is an important advantage.

The general design of the plant provides for a boiler room, a turbine room, and a switch-house, adjoining each other in the order named. Longitudinally the plant extends in an approximately northerly- southerly direction, parallel to the course of the river, the switch-house being located on the river side. The layout is such as to facilitate additions to the proposed plant when an increase in capacity becomes necessary, a symmetrical arrangement being pro-

vided for when the station has reached double the initial capacity.

The logical position of the turbine room is that nearest the river , for convenience and economy in the layout of the condenser tunnels. Owing to the shape of the property, it was found advisable to locate the switch-house on the river side of the turbine room. The boiler room is situated on the opposite side to gain the advantages afforded by the larg fuel storage area adjacent, and to permit the running of a spur from the railroad into the station and to the storage area. It is believed that the arrangement adopted will greatly facilitate the storage and subsequent handling of fuel.

In the plans for the buildings no especial attention was given to archetectural details, other than to provide such structures as would fullfil the required conditions, The nature of the soil necessitates, in the case of the heavier construction, the use piling. This, in connection with concrete footings to distribute the load more uniformly, provides substantial

foundations. In so far as practicable, reinforced concrete construction of floors, roofs, bunkers, gallerys, etc. is to be employed, since it is far preferable from the stand-points of cost, strength, and ability to withstand fire.

The boiler room is to be 136.5 feet long, 74.5 feet wide, and 68 feet high through the building center line. The addition of conveyor monitors brings the maximum height of building to 76.5 feet. A 20 foot basement is provided for the accomadation of piping and auxilary apparatus. At the northern end of the boiler room are located the stacks, two in number, which are of steel construction on brick bases. The height of bas base is 63.5 feet, sufficient to admit the entrance of the breeching from directly over the boilers. The inside diameter of the stack, at the base, is 19 feet, and the total height, above grates, is 200 feet. The turbine room is 136.5 feet long, 68.5 feet wide, 76 fet feet high, and has no basement, the turbine room floor being on a level with the basement floor of the boiler room. The switch-house is located adjacent

to the north end of the turbine room. It is 34.5 feet wide, 60. feet long, and 65 feet high. It is divided into three stories for the accomadation of the bus bars, switching and protective apparatus. The buildings are literally provided with side and end windows, and monitors for the purpose of ventilation and lighting.

The installation of apparatus is based on the unit system, modified sufficiently by the introduction of cross-connection to rapidly take care of emergencies which might arise. In the turbine room, the main auxillaries belonging to a unit are grouped about it and the boilers supplying the unit are located directly behind it. The main auxilaries include surface condensers, centrifugal circulating pumps, triplex air pumps, hot wells, boiler feed pumps, and step bearing pumps. In the basement of the boiler room are located the feed-water heaters, oil filters, accummulators, and emergency step bearing pumps. The arrangement is designed to simplify the piping details so as to lessen the cost of installation and

to the north end of the turbine room. It is 74.5 feet wide, 80. feet long, and 68 feet high. It is divided into three spaces for the accommodation of the two bays, switch and transformer apparatus. The buildings are literally provided with side and end windows, and ventilators for the purposes of ventilation and lighting.

The installation of apparatus is based on the unit system, modified materially by the introduction of cross-connections to provide here more of economy where slight extra. In the turbine room, the twin exciters delivered to a main bus-bar, about it and the battery supplied the wall are located directly behind it. The main auxiliary leading switches consisted, electrically operated, two-pole, triple throw knife switches, and ammeters for the purposes of ventilation and lighting. The buildings are literally provided with side and end windows. The bays, switch and transformer apparatus. The divided into three spaces for the accommodation of the feet wide, 80. feet long, and 68 feet high. It is to the north end of the turbine room. It is 74.5

maintenance, and to facilitate operating, especially in emergencies.

In the case of the auxillary electrical equipment the arrangement is similar, the exciters and exciter panels being located opposite to their respective generators. The layout of the switch-house is such as to provide for the subdivision of the total output of the station into three parts, to be operated separately, or to be paralleled as required.

In the selection of apparatus, the best modern practice was followed. The determination to use steam turbines instead of reciprocating engines as prime movers was based upon the former's well recognized advantages in the matter of first cost, amount of floor space required, labor necessary to operate, and increased purity of boiler feed water. Another important consideration is the high overload capacity of the steam turbine combined with uniformly high efficiency.

A turbine installation comprises three inits of the Curtis type rated at 4000 Kw. each. Allowing 50%

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ly in emergencies.

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ficiency.

A turbine installation comprises three units of

the Curtis type rated at 4000 Kw. each. Allowing 50%

over load capacity the maximum load on the station for one hour, may be 18000 KW. The turbines are five stage machines discharging into base condensers of the surface type. Station economy in the matter of boiler repairs, fuel economy, and reliability and life of the boiler plant depends to a large extent upon the choice of condenser. These items, in connection with the higher vacuum obtainable with surface condensers than with other types, and the determination to exclude economizers, decided the choice in favor of the surface condenser.

The generators are 3-phase, 25 cycle, 13,200 volt, star connected machines, feeding directly into the transmission system. The frequency was determined by the fact that the energy is supplied to a railway load through synchronous converters, which, in general, operate more satisfactorily on a low frequency. The use of high voltage machines eliminates the necessity for step-up transformers since the distance of transmission is comparatively short, and materially improves the regulation and efficiency of the system.

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for one hour, may be 18000 KW. The turbines are five
stage reaction direct-acting into main condensers of
the surface type. Steam is supplied by the battery of
boiler regular feed pumps, but reliability and
life of the boiler plant depends to a large extent upon
the choice of condenser. These items, in connection
with the higher pressure obtainable with surface con-
densers than with other types, put the determination
to overload conscientiously, decided the choice in favor of
the surface condenser.

The generators are 3-phase, 25 cycle, 13,800 volt,
water cooled machines, feeding directly into the
transmission system. The frequency was determined by
the fact that the energy is supplied to a mixed
load through synchronous converters, which, in general,
operate more satisfactorily at a low frequency. The use
of high voltage requires expensive insulators for
step-up transformers where the distance of transmis-
sion is considerable, which, and materially improves
the regulation and efficiency of the system.

The steam auxillaries, located in the turbine room, consist of a 22-inch centrifugal circulating pump, an Edwards triplex vacuum pump, and an outside packed plunger type boiler-feed pump. All this apparatus, including the step-bearing pump, is steam driven with the exception of the circulating pump, which is motor driven. The installation of steam driven auxillaries was made in the interests of economy, their exhaust steam being used to heat the boiler feed water, after which, it is discharged into the sewer. In addition, the initial cost of steam-driven is, in general, less than that of motor-driven auxillaries.

The step-bearing on the turbine is lubricated by oil at a pressure of 900 pounds per square inch. To eliminate the possibility of damage in case of a breakdown of the steam driven step-bearing pump, an emergency triplex pump, motor-driven, is installed in the basement of the boiler room and is arranged to start automatically upon a predetermined decrease in oil pressure. Accumulators are also installed in the boiler room, which are designed to maintain the oil pressure

The steam auxiliaries, located in the turbine room, consist of a motor-driven centrifugal circulating pump, an Edwards triplex vacuum pump, and an outside packed plunger type motor-feed pump. All this apparatus, including the step-bearing pump, is steam driven with the exception of the circulating pump, which is motor driven. The lubrication of steam driven auxiliaries was made in the basement of engine, that is exhaust steam being used to heat the boiler feed water after which, it is discharged into the sewer. In addition, the initial head of steam-lifted is conserved. less than that of motor-driven auxiliaries.

The step-bearing on the impeller is lubricated by oil at a pressure of 600 pounds per square inch. To eliminate the possibility of failure in case of a breakdown of the steam driven step-bearing pump, an motor-driven triplex pump, is installed in the basement of the boiler room and it operated to start automatically upon a predetermined decrease in oil pressure. Solenoid valves are also installed in the boiler room, which are designed to maintain the oil pressure

on the step while the unit is being shut down.

The excitation for each of the generators is supplied by a 50 KW. induction motor-driven exciter, which receives energy from a 3-phase step-down transformer located in the switch-house. In case of trouble with the motor driven exciters, a 250 KW. steam-driven D.C. generator is capable of taking the entire excitation load in addition to the normal station power and and lighting load.

The cooling water for the condensers is supplied from and discharged into concrete tunnels, running through the center of the turbine room. The intake tunnel receives its water through a screened intake on the upstream side. A dam is provided to prevent any of the warm discharge water from the adjacent outlet tunnel being taken through the intake.

The oil filtering system for the plant is located in the basement of the boiler room, which also accomadates the feed water heaters. The boilers on the floor above are in two rows parallel to the turbine room and are twelve in number. The four boilers supplying

on the step while the unit is being shut down.

The excitation for each of the generators is supplied by a 80 KW. induction motor-driven exciter, which receives energy from a 3-phase step-down transformer located in the switch-house. In case of trouble with the motor during operation, a 600 H.P. steam-driven D.C. generator is capable of taking the entire excitation load in addition to the normal exciter load lower end and transmission lines.

The poles which connect the condensers to switched from and discharge into concrete tunnels, running through the bottom of the station room. The intake tunnel receives its water through a screened intake on the upstream side. A dam is provided to prevent any of the warm discharge water from the discharge outlet turned back into the intake.

The oil filtering system for the plant is located in the basement of the boiler room, which also accommodates the feed water heaters. The heaters on the 2nd floor are in two rows parallel to the turbine room and are twelve in number. The four heaters supplying the

each unit consist of two directly behind the unit and the two boilers opposite. The boilers are of the Babcock and Wilcox water tube type, rated at 600 H.P., and are equipped with superheaters designed to raise the temperture of the steam to 150 degrees superheat. This degree of superheat is adopted to prevent trouble which, in the case of excessive tempertures, is likely to occur with flanged joints, valves, and in the steam cylinders of the auxillaries. The layout of boilers is such as to reduce to a minimum the amount of piping above the-m and to greatly simplify the general piping arrangements.

The boilers are supplied from two rows of concrete-steel bunkers directly above. These bunkers have a storage capacity sufficient to carry the plant for four days. They are supplied by a conveyor system having having an hourly capacity of 75 tons each. The boilers are equipped with automatic stokers of the chain grate type, driven by small engines which are located on overhead platforms at each end of the firing alley.

The ashes and fine coal from the grates are receive

ed in separate bunkers in the basement which discharge into the conveyors, and are transfered to the proper bunkers in the train shed, adjoining the boiler room. The ash bunkers in the train shed are arranged to discharge their contents directly into cars below. The coal is received in the same shed. Coal delivered in dump cars is emptied into hoppers directly below, from which it runs through a motor-driven crusher onto the c conveyor. If the coal is not in dump cars, it is handled by a one-ton grab bucket, operated electrically from an overhead traveling crane.

The electrical equipment located in the switch-house is controlled from an enclosed operating gallery on the east wall of the turbine room. On this gallery is installed the main switchboard, comprising generator, line, and transformer panels. The switchboard gallery communicages directly with the second floor of the switch-house and affords the operator an unobstructed view of the entire turbine room.

The generator leads are carried in bituminized fibre conduit, laid in the basement floor, to the

main generator oil switches, which are located on the main floor of the switch-house. The generator switches connect through selector switches to two complete sets of main bus bars which may be operated independently or in parallel. The bus bars then connect through selector switches to the main line switches of the three transmission circuits. Both sets of main bus bars are also provided with bus junction switches to take care of situations demanding the separate operation of lines or units. The arrangement is intended to provide for the maximum reliability and flexibility of operation.

The switching equipment is solenoid operated and is controlled directly from the generator and line panels on the switchboard gallery.

In addition to the generator switches the first floor of the switch-house provides for the installation of the 200 KW. transformer supplying power to the exciter sets, the generator field rheostats, and the neutral ground resistance. The second floor accomadates the selector and junction switches and main bus bars;

main generator oil switches, which are located on the main floor of the switch-house. The generator switches connect through selector switches to two complete sets of main line relays, any of which may be operated interchangeably or in parallel. The two sets then connect through selector switches to the main line switches of the three transmission circuits. Both sets of main line relays are also provided with the ignition switches to take care of situations demanding the maximum operation of lines or units. The arrangement is intended to provide for the maximum reliability and flexibility of operation.

The switching equipment is solenoid operated and is controlled directly from the generator and line panels on the switching gallery.

In addition to the generator switches the first floor of the switch-house provides for the installation of the 2300 kv. transformer supplying power to the exciter sets. The secondary feeder circuits, and the neutral ground switches. The second floor accommodates the exciter and induction motor field rheostats;

the third , the line switches, choke coils, and lightening arresters. The transmission circuits are led out of the southern wall of the switch-house through glass bulls- eyes to the lines which run west to the Rock Island right of way.

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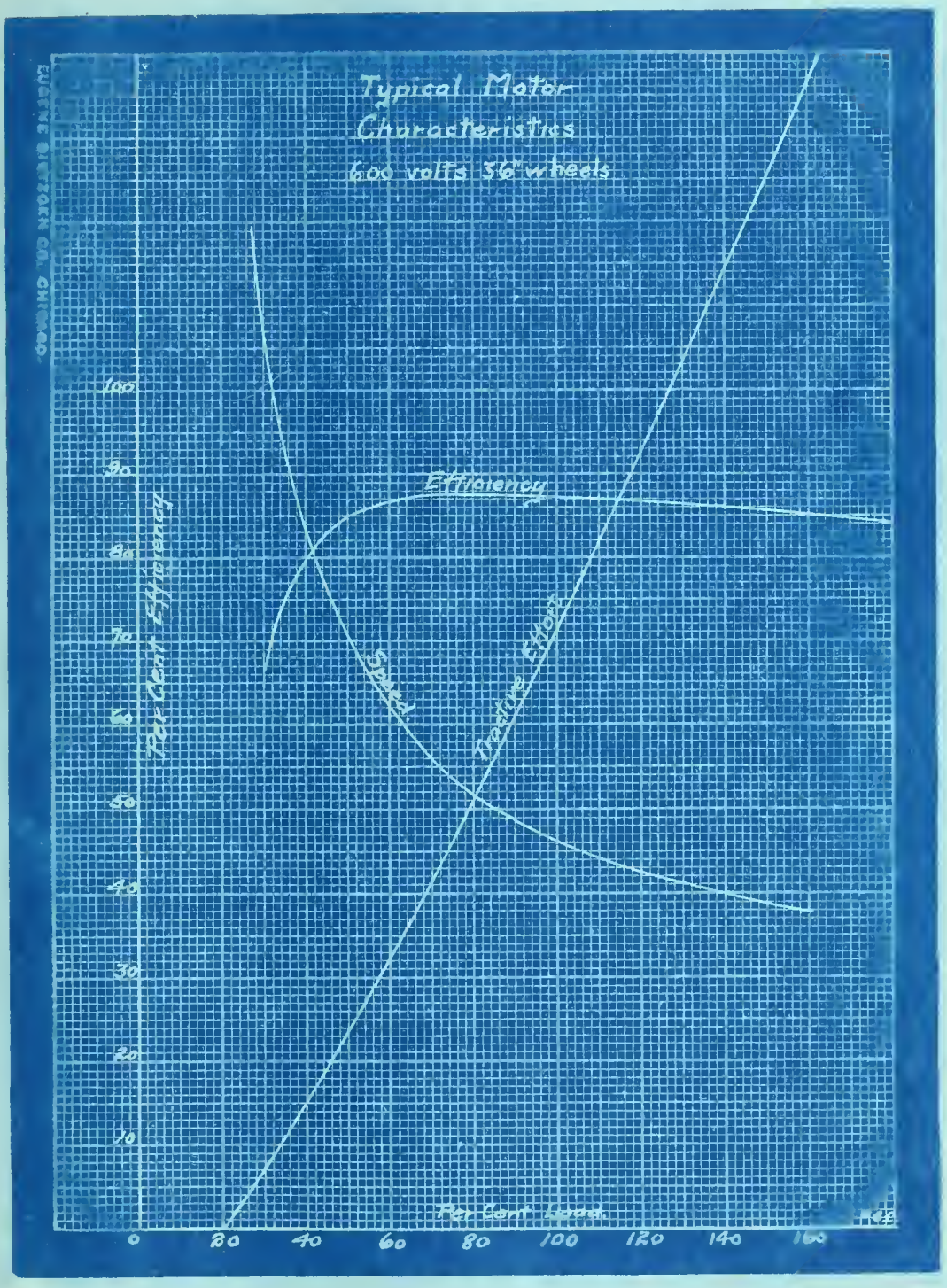
Typical Motor
Characteristics
600 volts 36" wheels
Efficiency
Speed
Tractive effort
Per cent efficiency
Per cent speed
Per cent tractive effort
0
20
40
60
80
100
120
140
160
EUGENE DIETZGEN CO. CHICAGO

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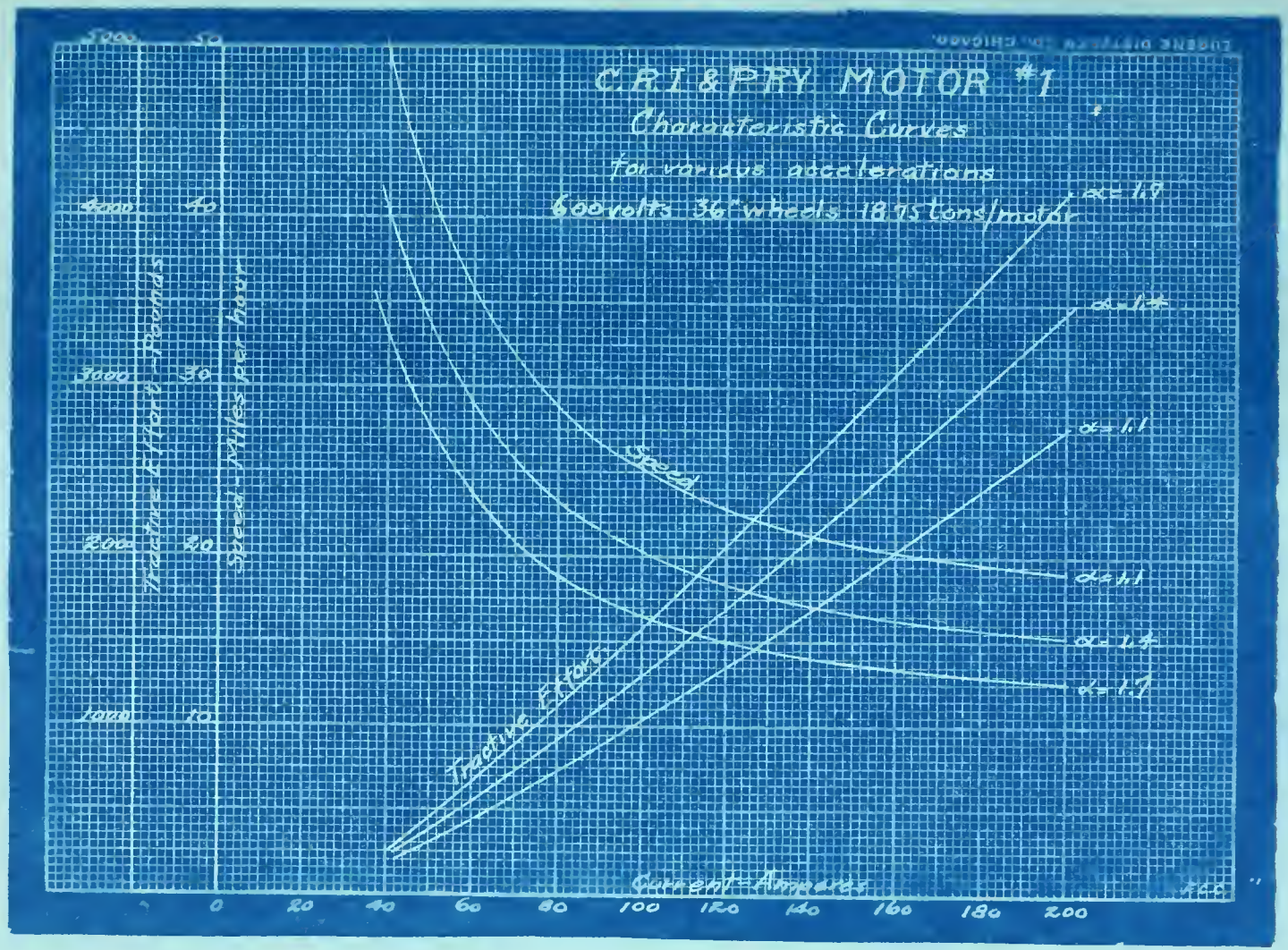
C.R.I. & P.R.Y. MOTOR #1
Characteristic Curves
for various accelerations
600 volts 36" wheels 18.75 tons/motor
Speed
Tractive Effort
Tractive Effort in Pounds
Speed in Miles per Hour
Current in Amperes
α = 1.0
α = 1.2
α = 1.1
α = 1.3
α = 1.4
α = 1.7
5000
4000
3000
2000
1000
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200

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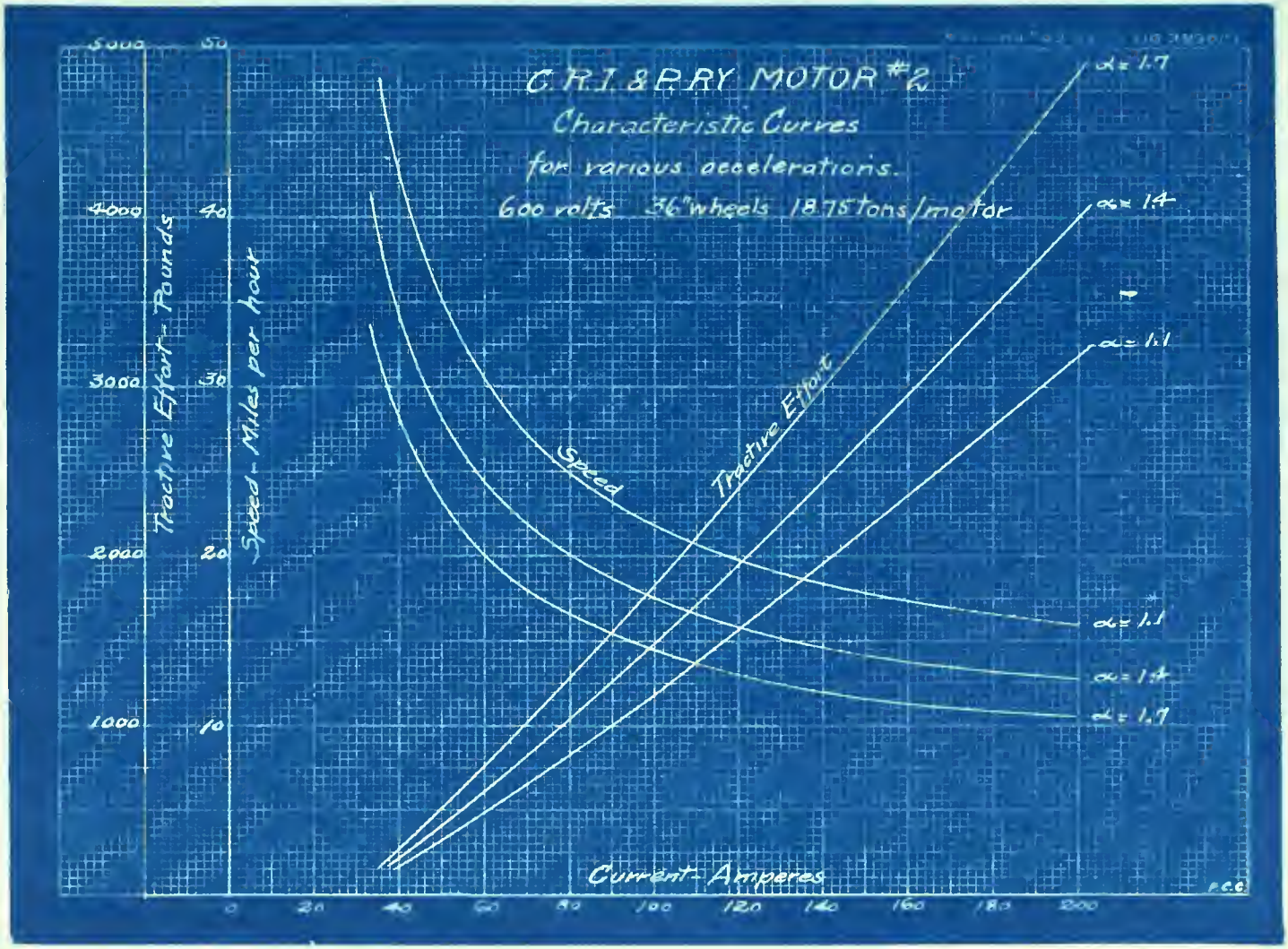
C.R.I.&P.RY MOTOR #2
Characteristic Curves
for various accelerations.
600 volts 36" wheels 18.75 tons/motor
Tractive Effort - Pounds
Speed - Miles per hour
Current - Amperes
Speed
Tractive Effort
α = 1.7
α = 1.4
α = 1.1
α = 1.1
α = 1.4
α = 1.7
5000
4000
3000
2000
1000
50
40
30
20
10
0
20
40
60
80
100
120
140
160
180
200

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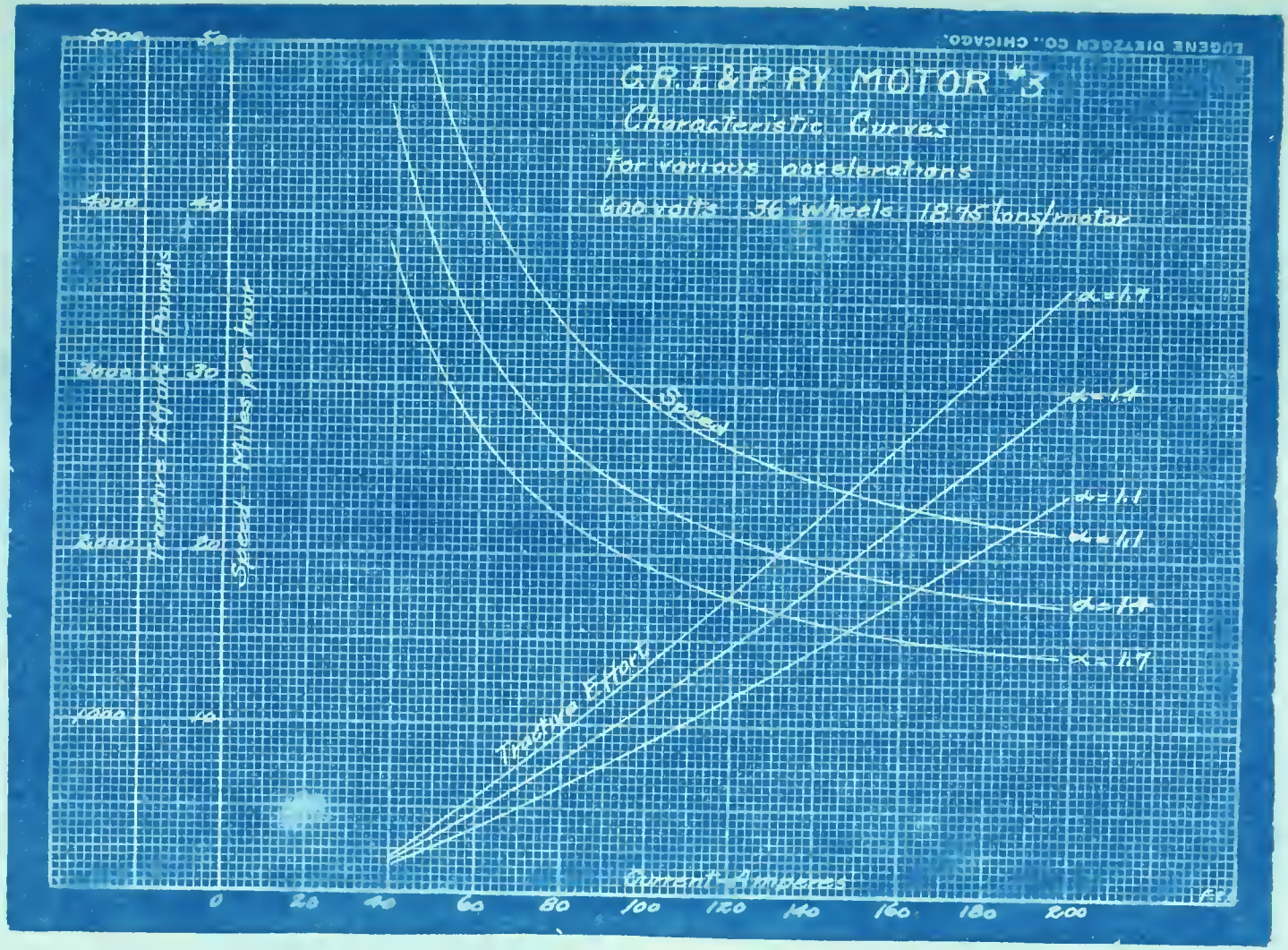
C.R.I.&P.RY MOTOR #3
Characteristic Curves
for various accelerations
600 volts 36" wheels 18.78 ton locomotive
Speed
Tractive Effort
Current Amperes
Speed in Miles per Hour
Tractive Effort in Pounds
0
20
40
60
80
100
120
140
160
180
200

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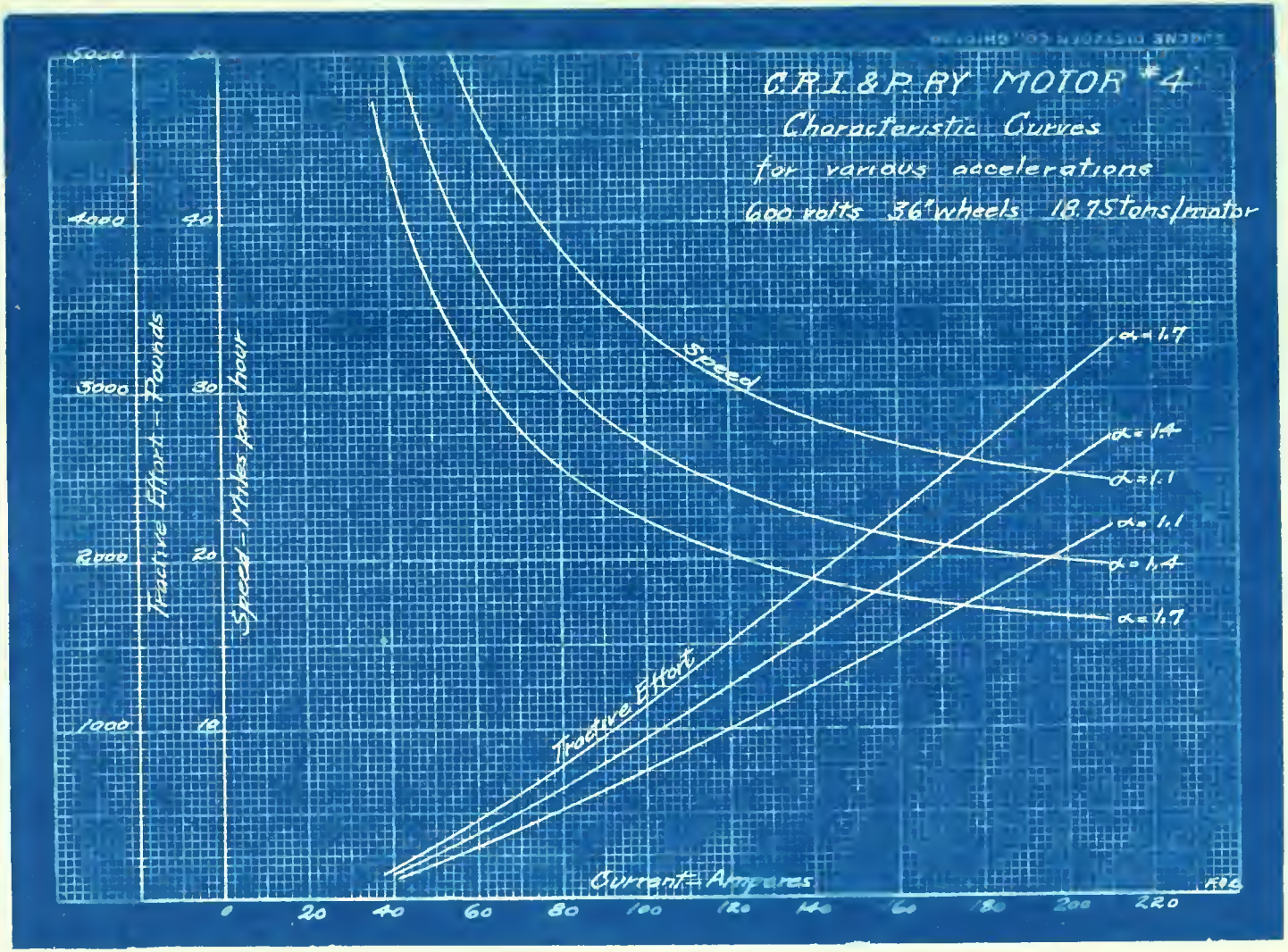
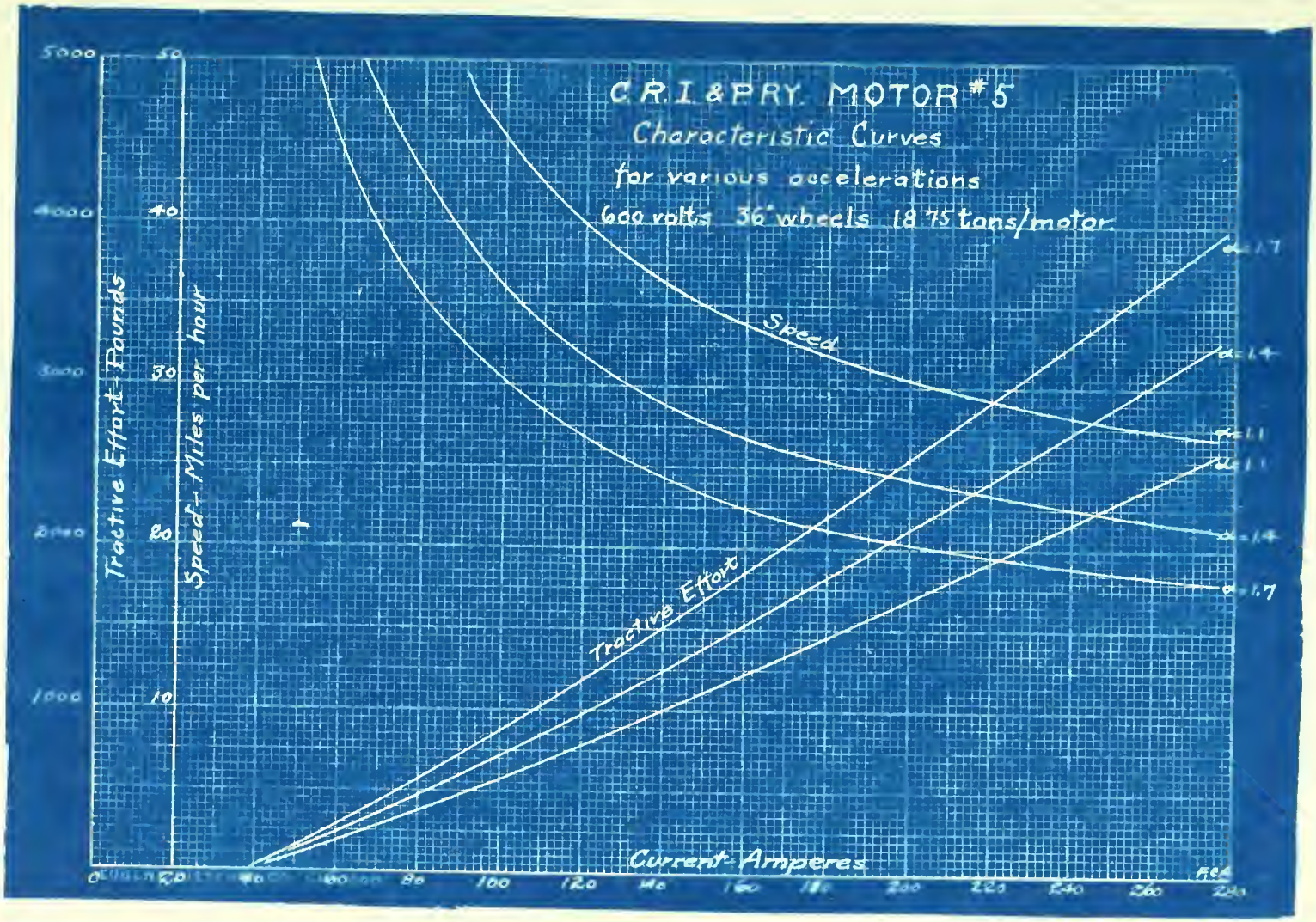
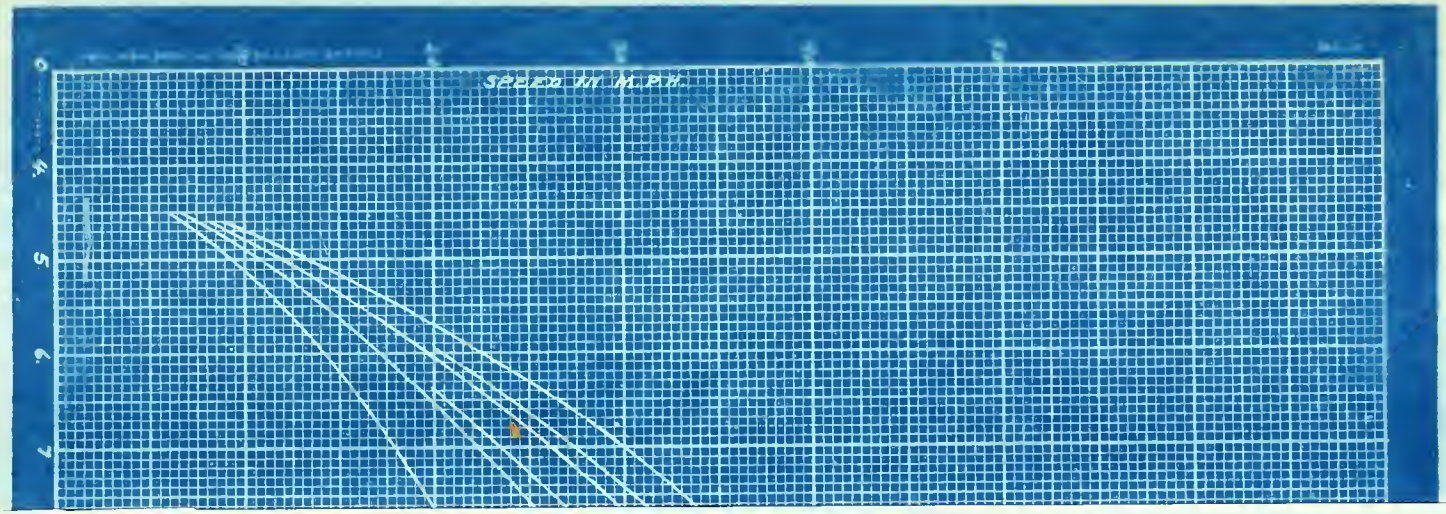

C.R.I.&P. RY MOTOR #4
Characteristic Curves
for various accelerations
600 volts 36" wheels 18.75 tons/motor
Tractive Effort - Pounds
Speed - Miles per hour
5000
4000
3000
2000
1000
40
30
20
10
Speed
α = 1.7
α = 1.4
α = 1.1
α = 1.1
α = 1.4
α = 1.7
Tractive Effort
Current - Amperes
0
20
40
60
80
100
120
140
160
180
200
220

ARMOUR
INSTITUTE OF TECHNOLOGY


C.R.I.&P.RY. MOTOR #5
Characteristic Curves
for various accelerations
600 volts 36" wheels 18.75 tons/motor.
Tractive Effort-Pounds
Speed-Miles per hour
Current-Amperes
Speed
Tractive Effort
a=1.7
a=1.4
a=1.1
a=1.1
a=1.4
a=1.7
5000
4000
3000
2000
1000
50
40
30
20
10
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY


SPEED IN M.P.H.

ARMOUR
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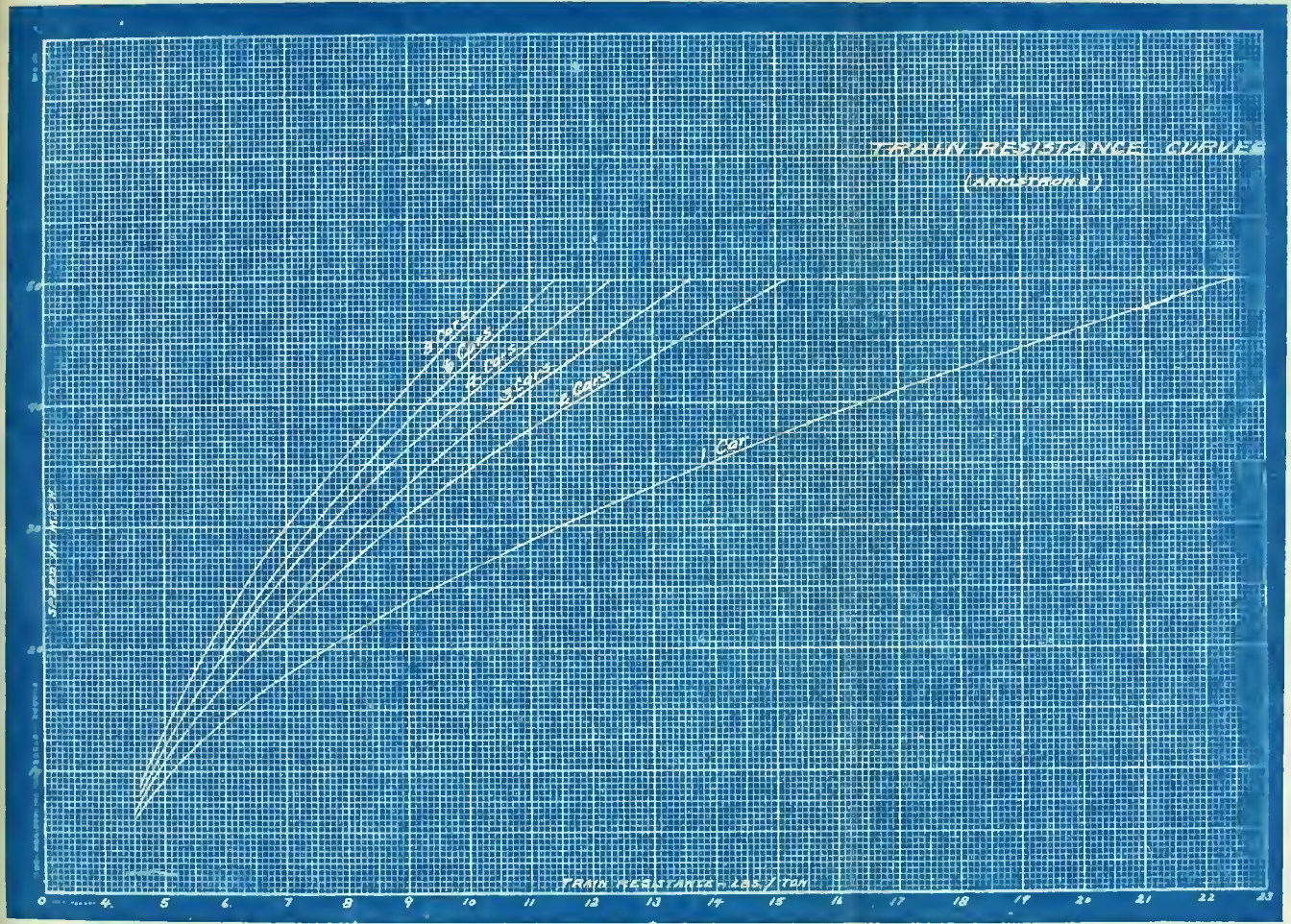
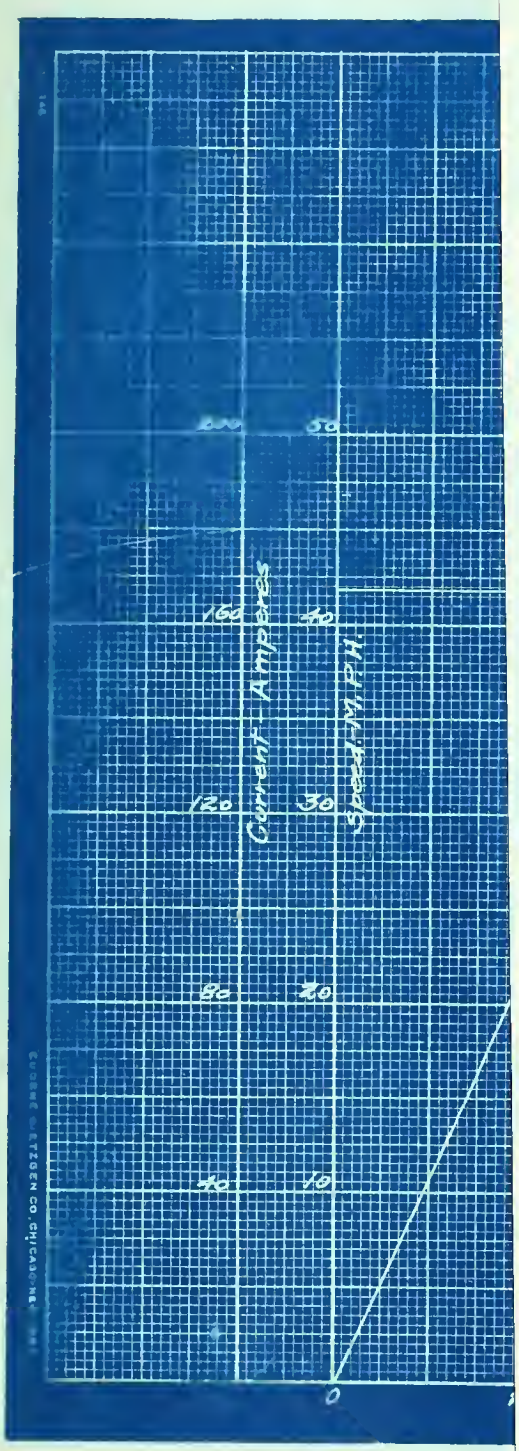
LIBRARY


TRAIN RESISTANCE CURVES
(ARMSTRONG)
TRAIN RESISTANCE - LBS. / TON
0
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
1 CAR
2 CARS
3 CARS
4 CARS
5 CARS
6 CARS

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.



C.R.I.+P. RY. MOTOR #1

SPEED-TIME CURVE * TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

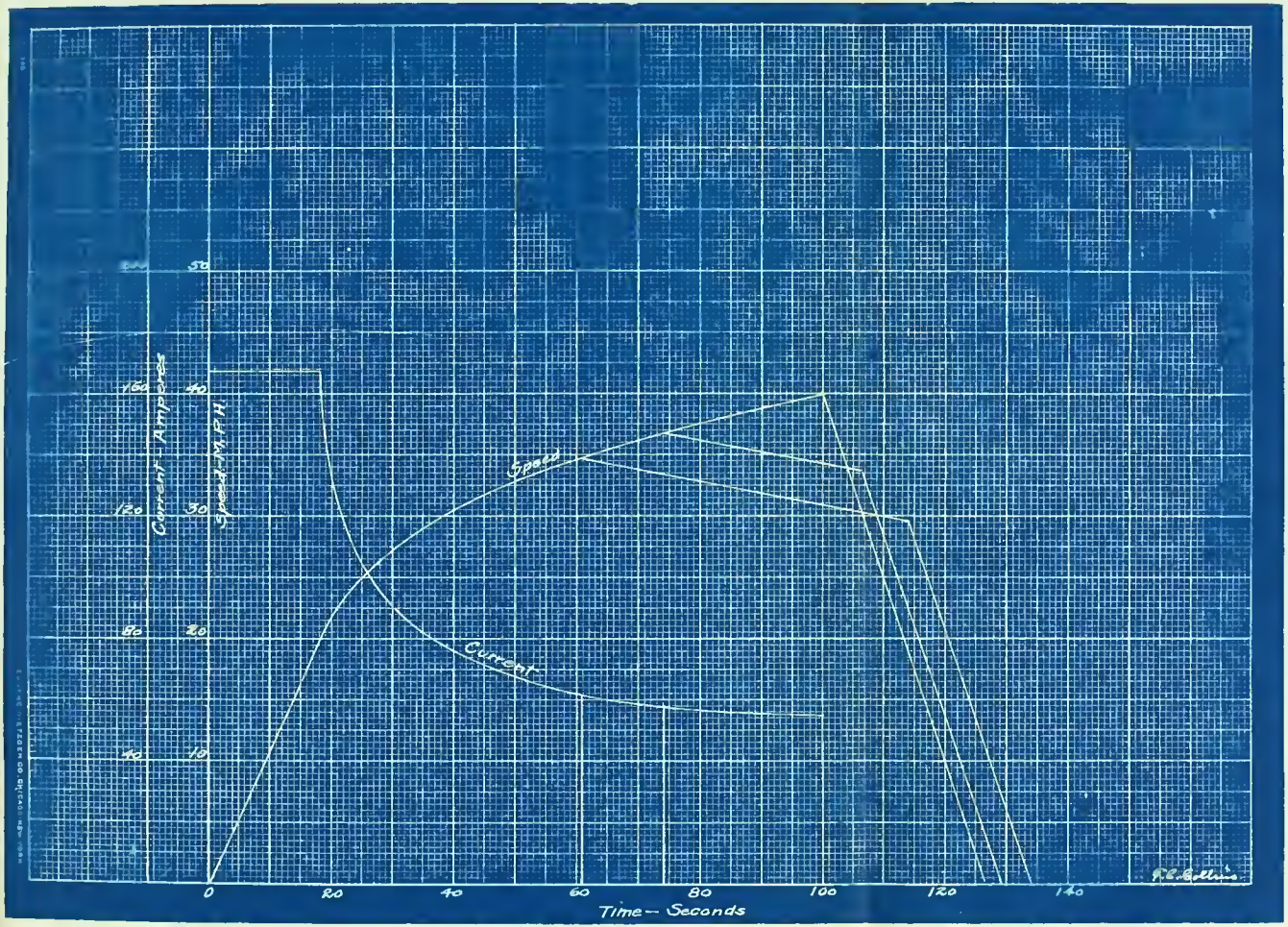
α = MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

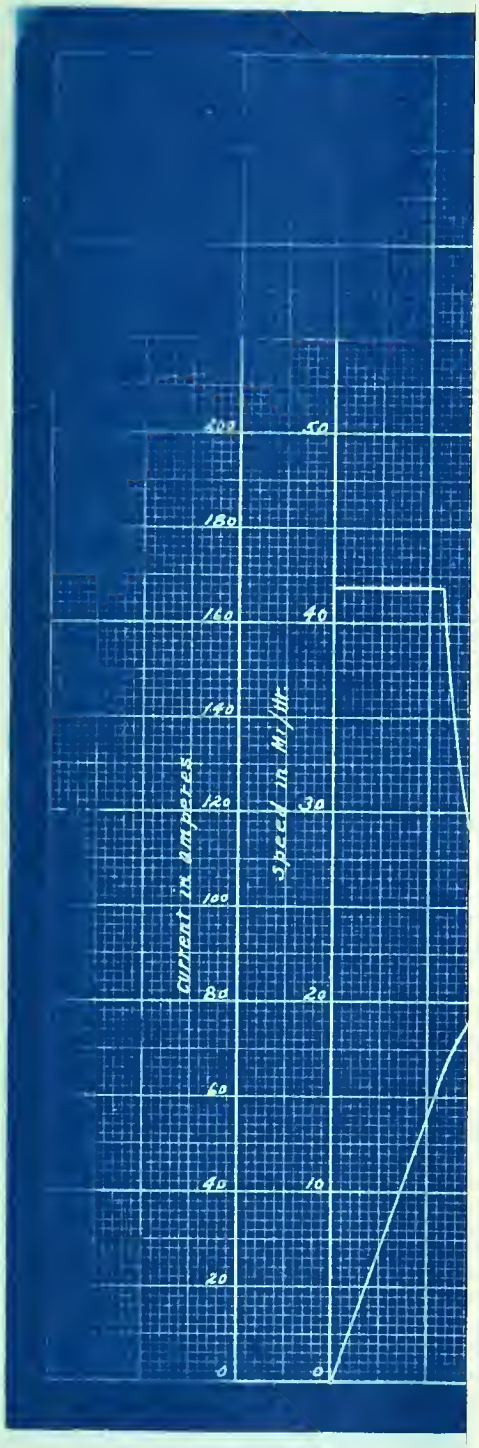
COASTING.	0 %	25 %	40 %
SCHED. SPEED	23		22.7
WT. HRS./TON MI.	92.5	69.4	62.
$\sqrt{\text{MEAN } I^2}$	92.7	75.	73.5

S.A.S.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.


Current - Amperes
Speed M.P.H.
Speed
Current
0
20
40
60
80
100
120
140
Time -- Seconds

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.



C.R.I.&P. RY. MOTOR #

SPEED-TIME CURVE ✱ TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

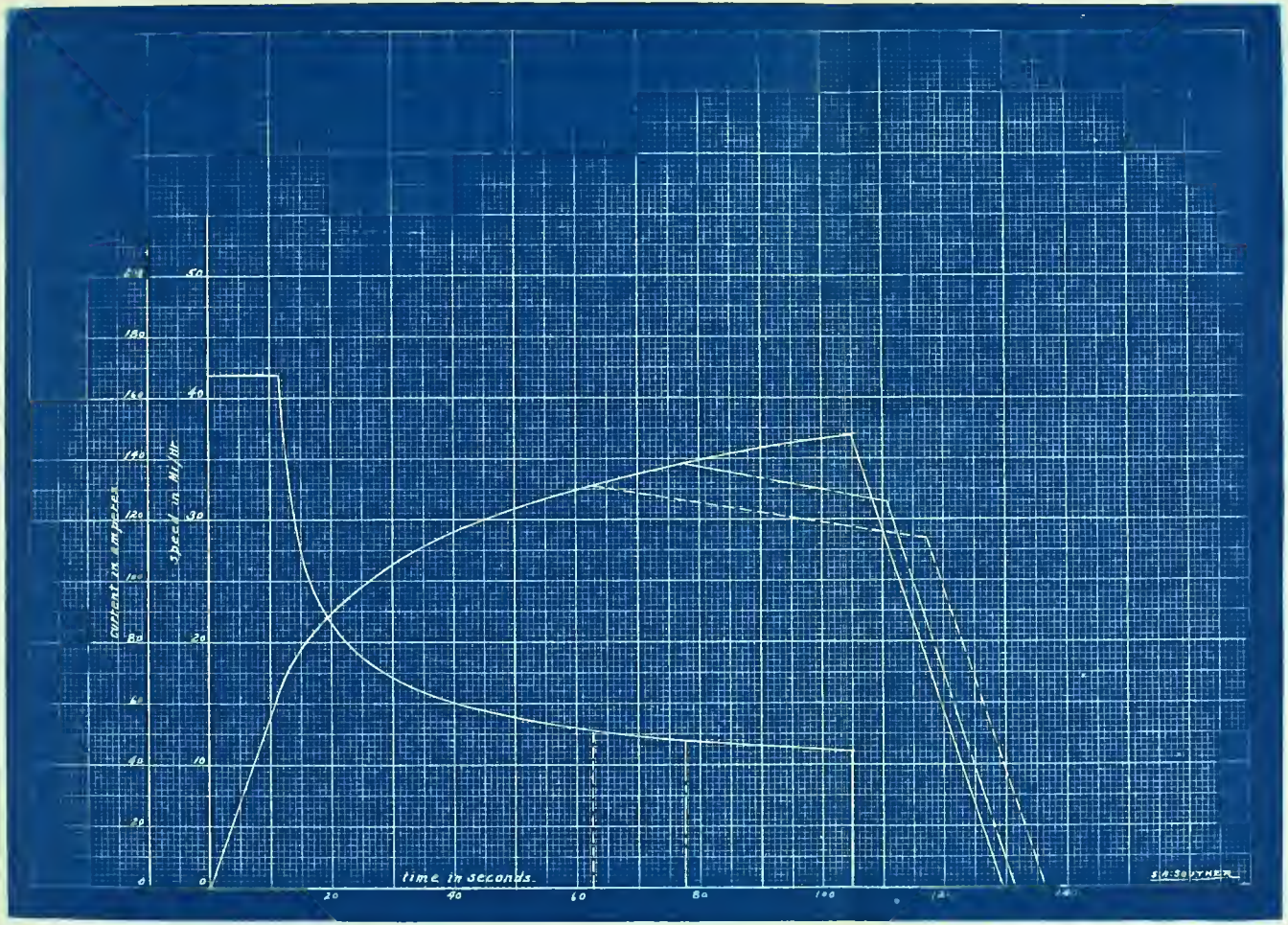
α = [illegible] MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

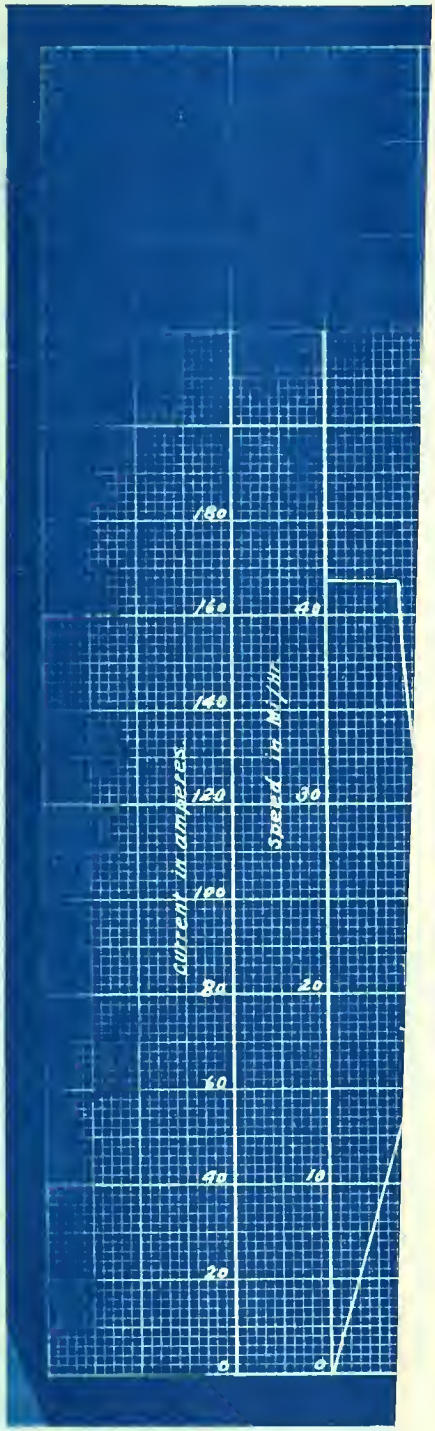
COASTING	0 %	25 %	40 %
SCHED. SPEED	[illegible]	22.6	21.9
WT. HRS./TON MI.	70.2	[illegible]	51.7
$\sqrt{\text{MEAN } I^2}$	[illegible]	65.1	62.1

S.O.S.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.


Current in Amperes
Speed in M.P.H.
time in seconds.
0
20
40
60
80
100
120
140
160
180
200
10
30
50
S.A. SOLTNER

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY



C.R.I.+P. RY. MOTOR #1

SPEED-TIME CURVE + TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

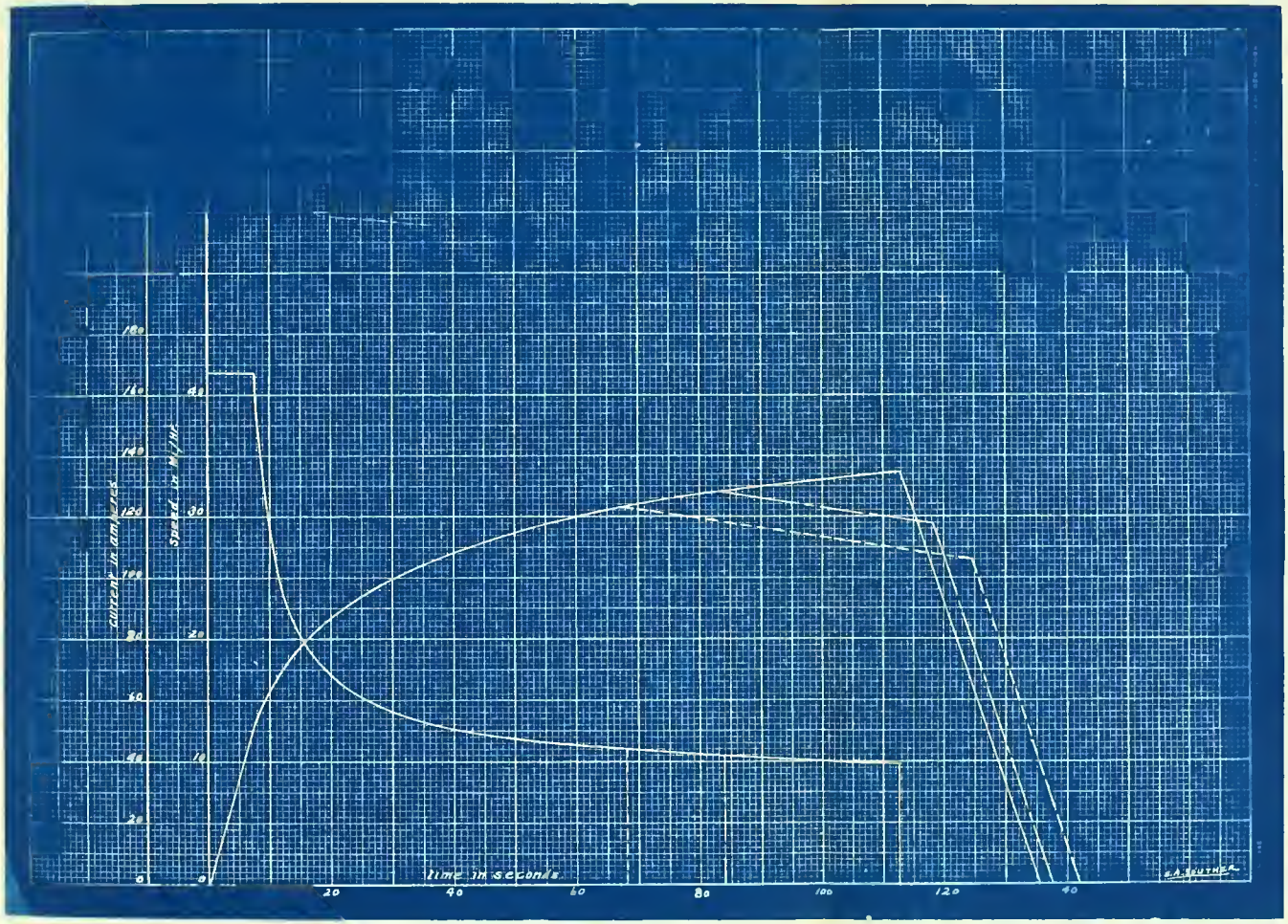
α = 1.7 MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

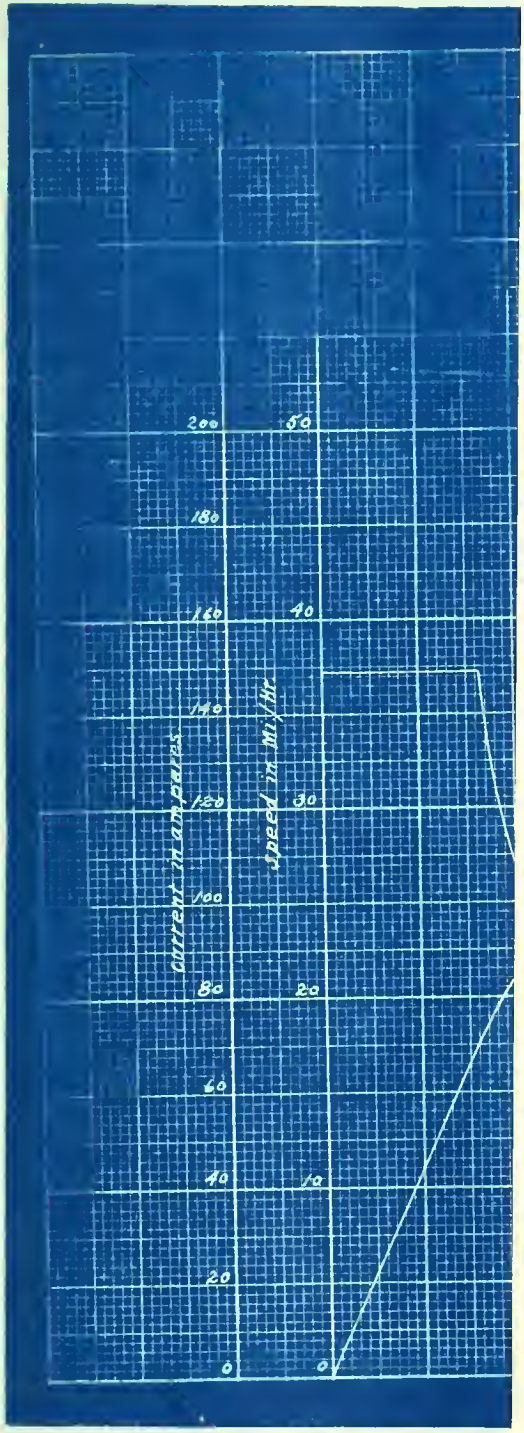
COASTING	0 %	25 %	40 %
SCHED. SPEED	21.97	21.7	21.1
WT. HRS./TON MI.	63.5	53.3	46.1
$\sqrt{\text{MEAN } I^2}$	59.2	56.9	53.8

S.A.S.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY


Speed in M./hr.
Current in amperes
Time in seconds
E.A. Sutner

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.



C.R.I.+P. RY. MOTOR # 2

SPEED-TIME CURVE * TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

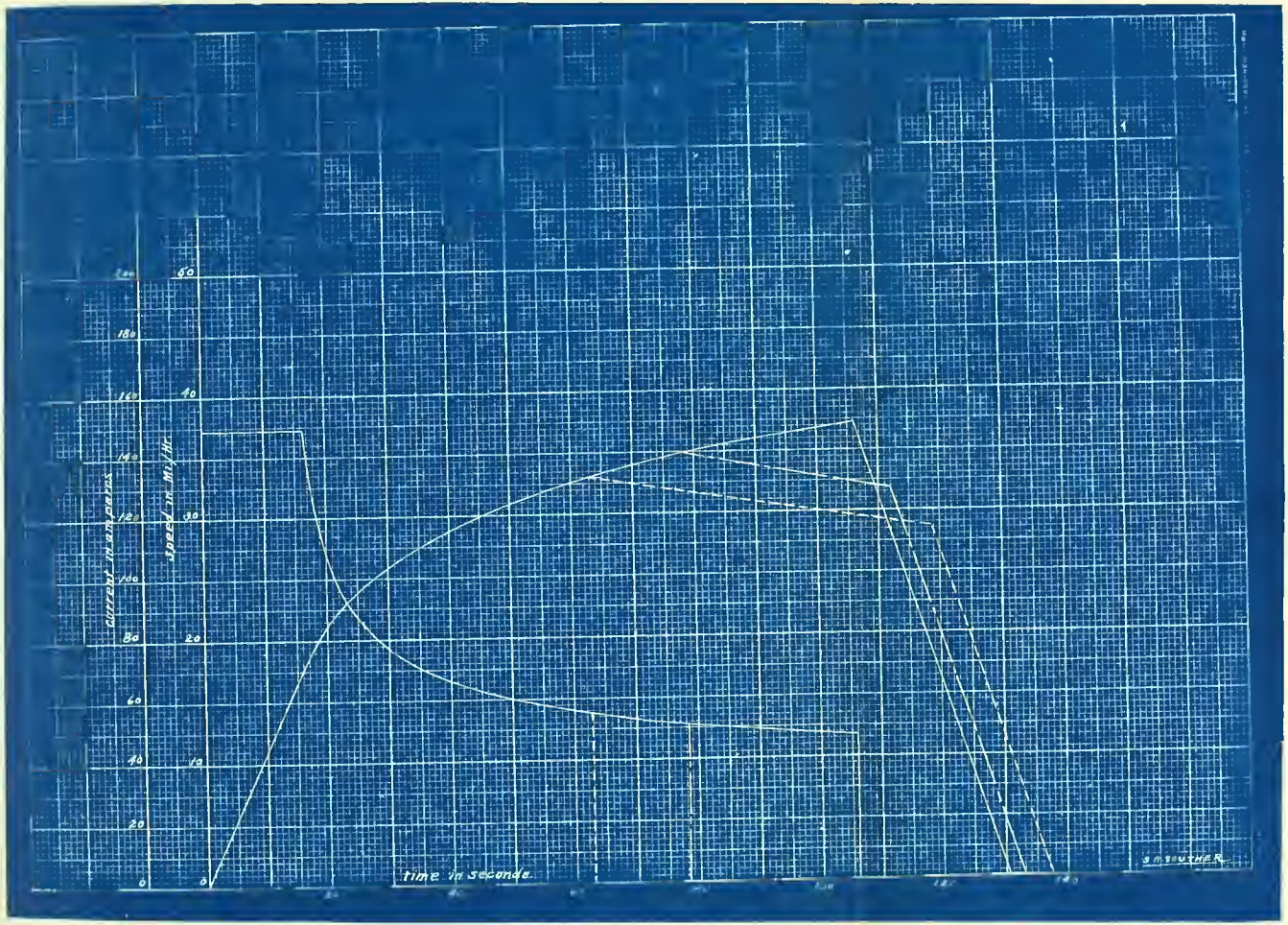
α = 1.1 MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	22.7	22.3	21.7
WT. HRS./TON MI.	75	62.3	54.8
$\sqrt{\text{MEAN } I^2}$	70.4	66.6	63.4

S.P.S.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.


Current in amperes
Speed in M.P.H.
time in seconds
S.M. SOUTHER

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.

C.R.I.+P. RY. MOTOR # 2

SPEED-TIME CURVE + TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

α = 1 1/2 MI./HR./SEC. B.R. = 1.5 MI/HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	22	21.5	20.8
WT. HRS./TON MI.	65	54	47.6
$\sqrt{\text{MEAN } I^2}$	58.8	50.4	52

ARMOUR
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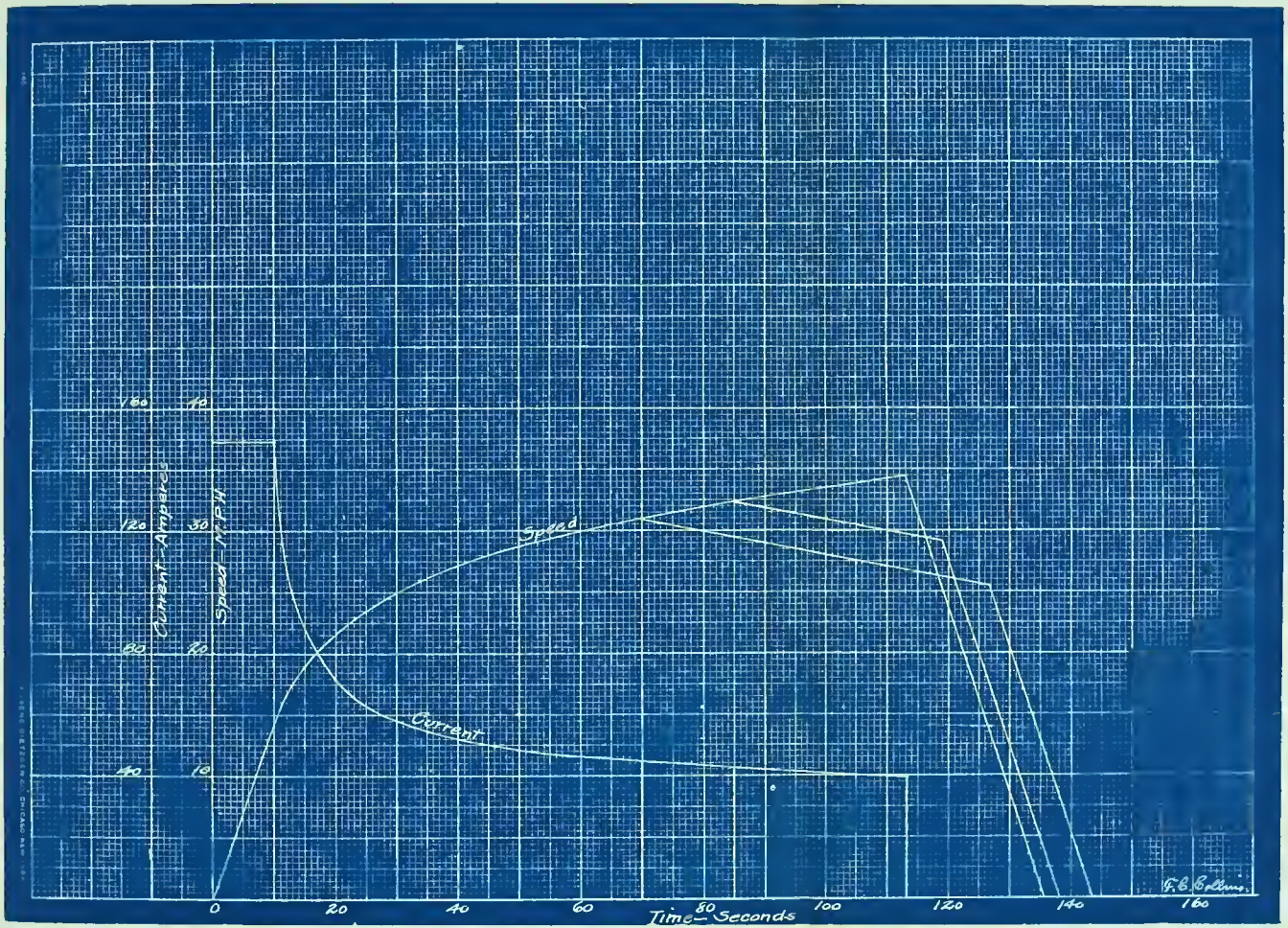
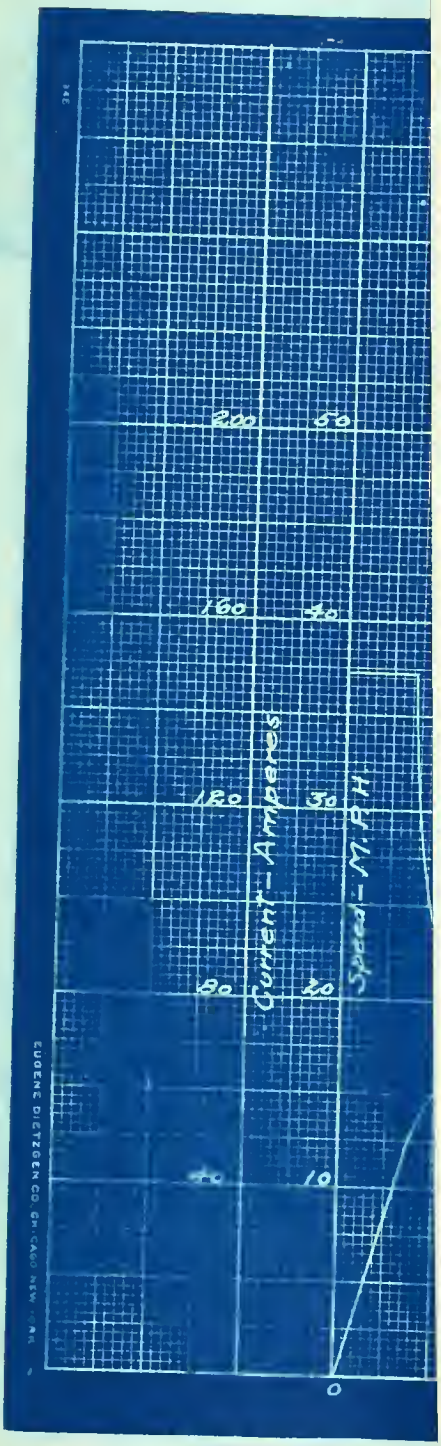
LIBRARY.


Current - Amperes
Speed - R.P.M.
Speed
Current
Time - Seconds
0
20
40
60
80
100
120
140
160
180
120
80
40
40
30
20
10

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY



C.R.I.+P. RY. MOTOR # 2.

SPEED-TIME CURVE + TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

α = 1.7 MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	20.95	20.7	20.1
WT. HRS./TON Mi.	51	45	43.3
$\sqrt{\text{MEAN } I^2}$	50	47.6	45.2

ARMOUR
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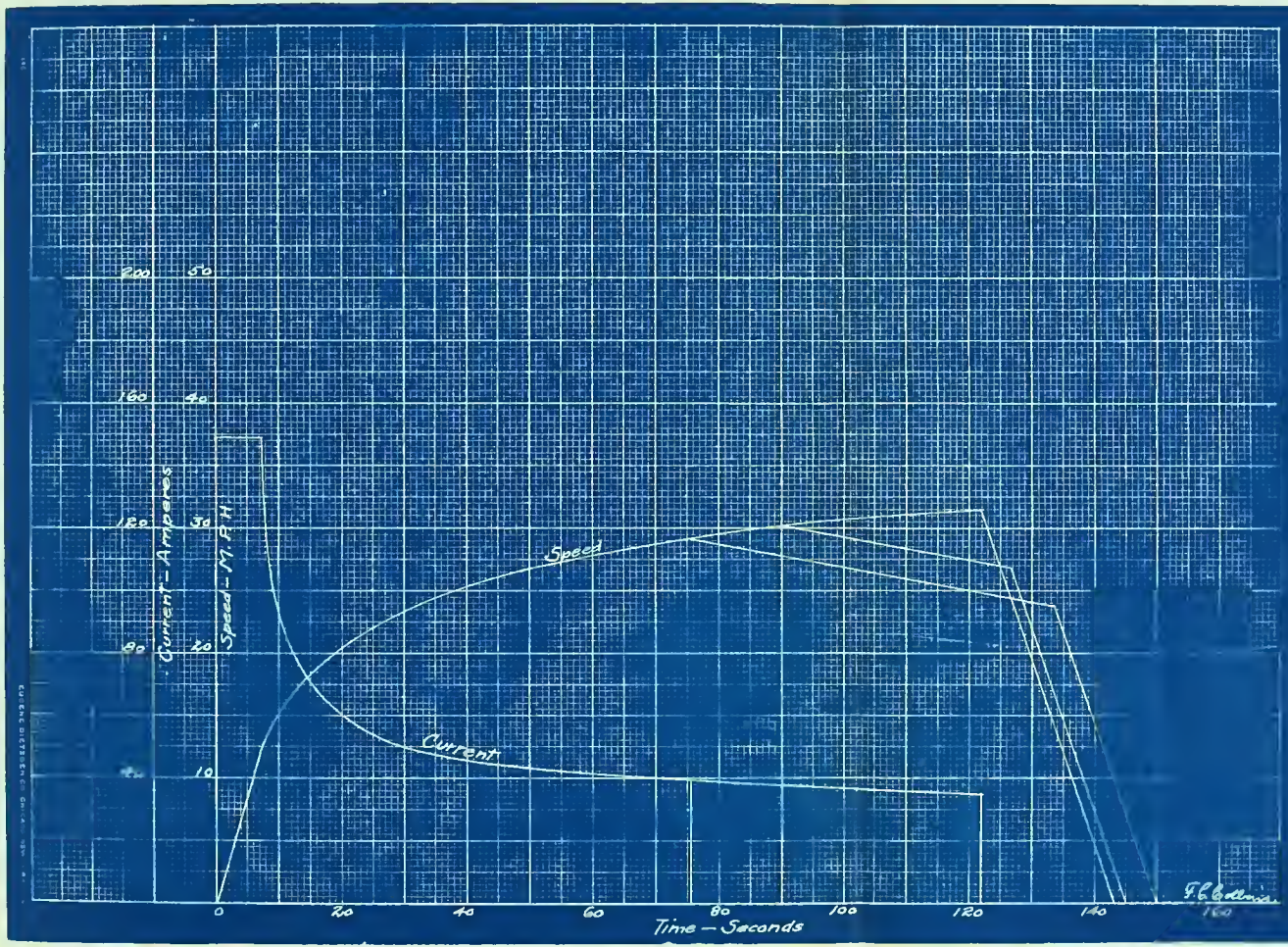
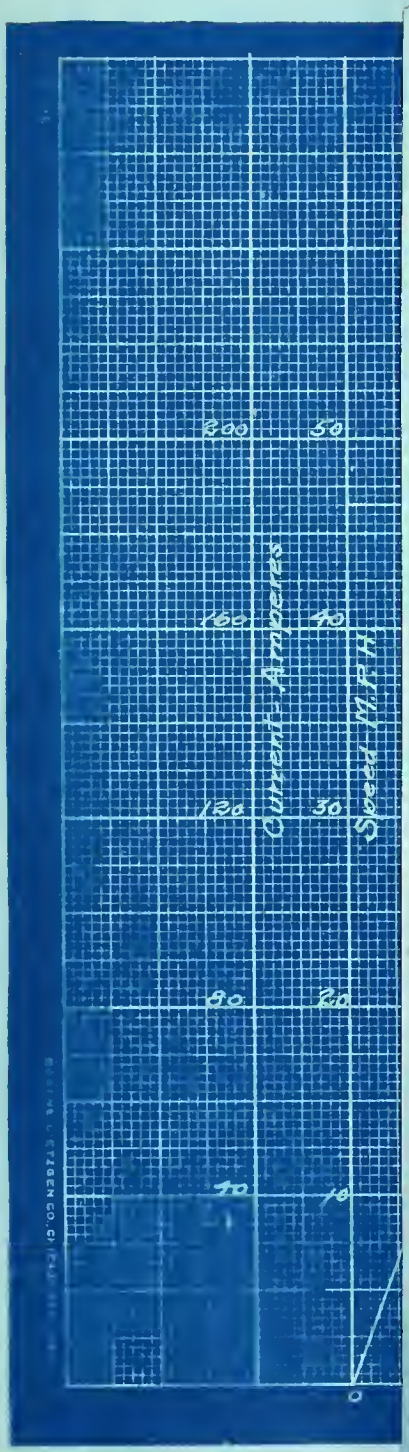
LIBRARY


Current – Amperes
Speed – M.P.H.
200
160
120
80
40
50
40
30
20
10
Speed
Current
0
20
40
60
80
100
120
140
160
Time – Seconds

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY



C.R.I.&P.RY. MOTOR # 3

SPEED-TIME CURVE * TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR, 2 TRAILERS } 18.75 TONS/MOTOR.

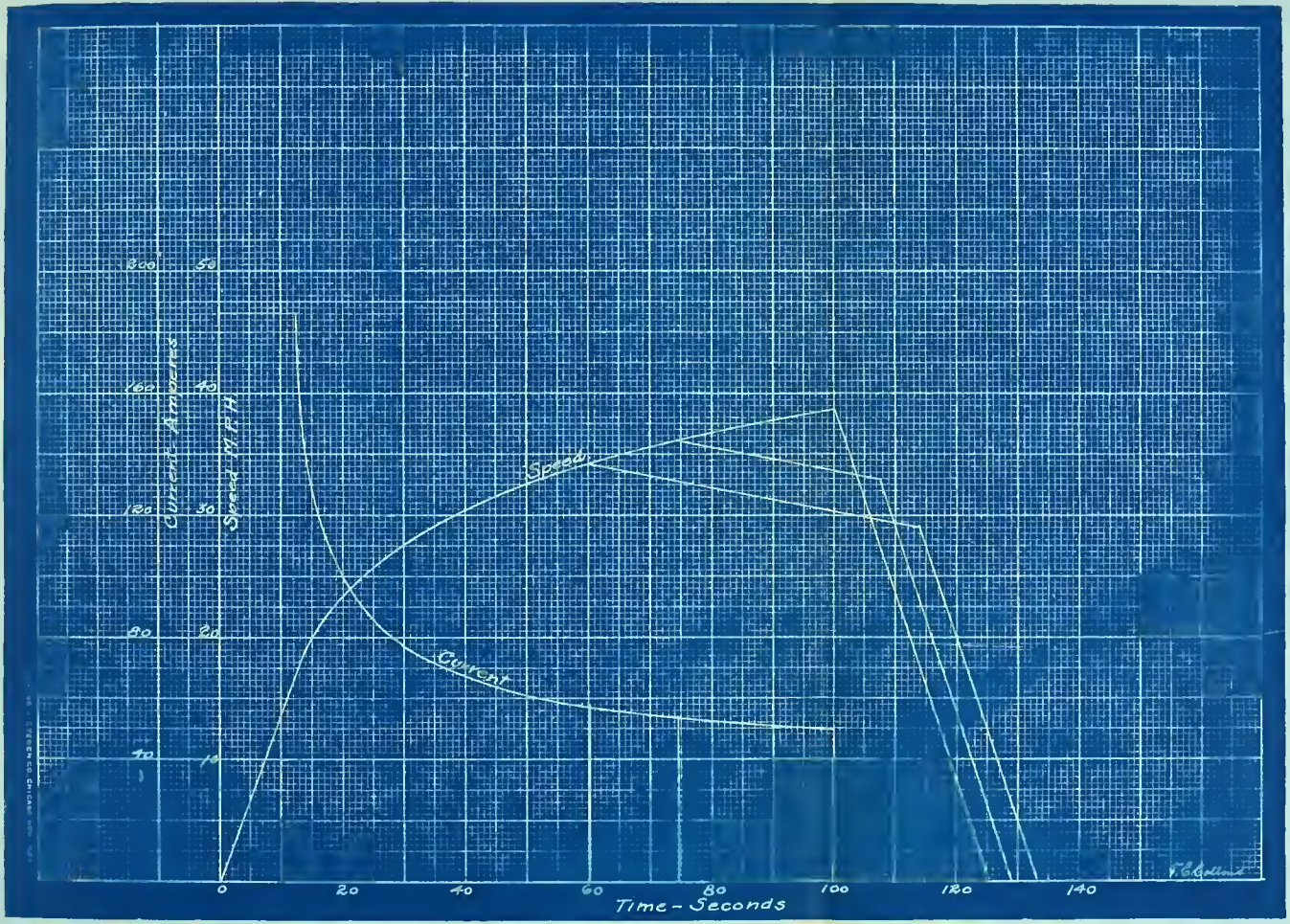
α = 1.4 MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	23.4	23.	22.8
WT. HRS./TON MI.	76.4	64.4	57.2
$\sqrt{\text{MEAN } I^2}$	74.9	71.5	69.5

S.A.S.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY


Speed
Current
Current in Amperes
Speed in M.P.H.
200
160
120
80
40
50
40
30
20
10
0
20
40
60
80
100
120
140
Time - Seconds

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

C.R.I.+P. RY. MOTOR # 3

SPEED-TIME CURVE + TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

α = 1.7 MI./HR./SEC. B.R. = 1.5 MI/HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	22.6	22.3	21.6
WT. HRS./TON MI.	65	58.8	57.0
$\sqrt{\text{MEAN } I^2}$	66	63.5	60.2

S.A.S.

ARMOUR
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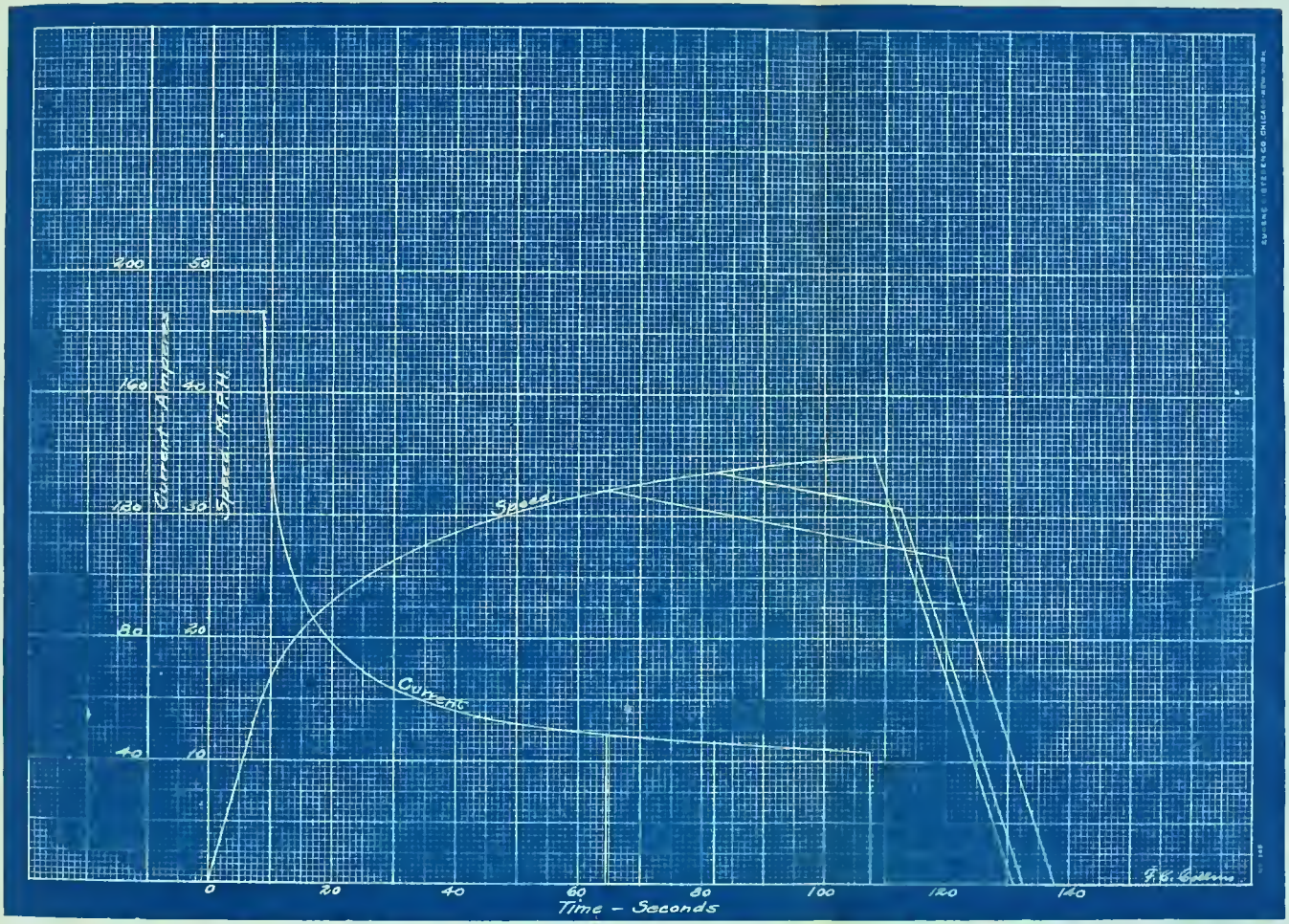
LIBRARY.


Current - Amperes
Speed - M.P.H.
400
160
120
80
40
30
40
30
20
10
Speed
Current
0
20
40
60
80
100
120
140
Time - Seconds

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY

C.R.I.+P. RY. MOTOR # 3

SPEED-TIME CURVE + TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

α = 1.1 MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	24	23.5	22.9
WT. HRS./TON Mi.	91.8	77.5	68.8
$\sqrt{\text{MEAN } I^2}$	92.6	87.8	84.

S.A.S.

ARMOUR
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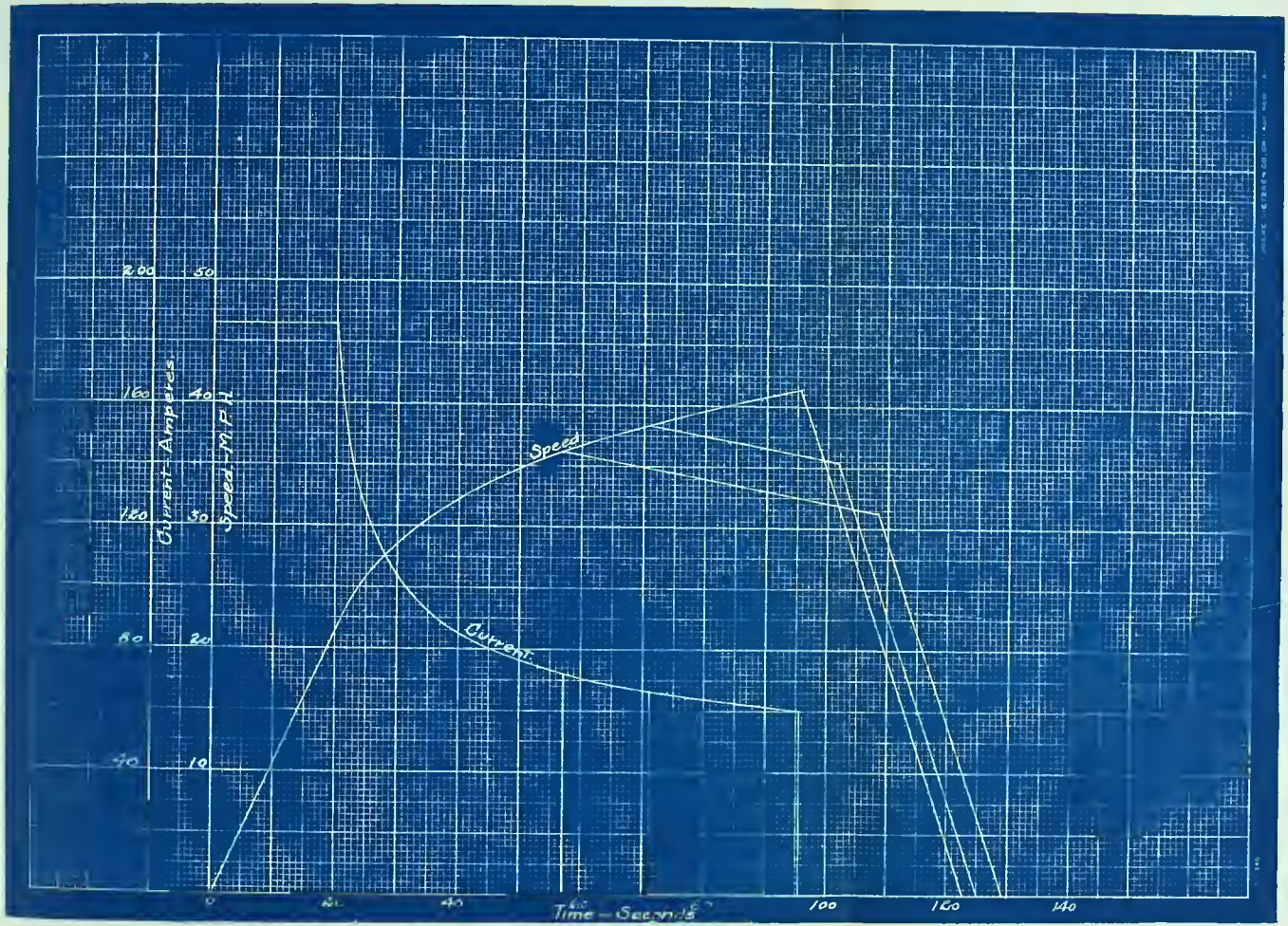
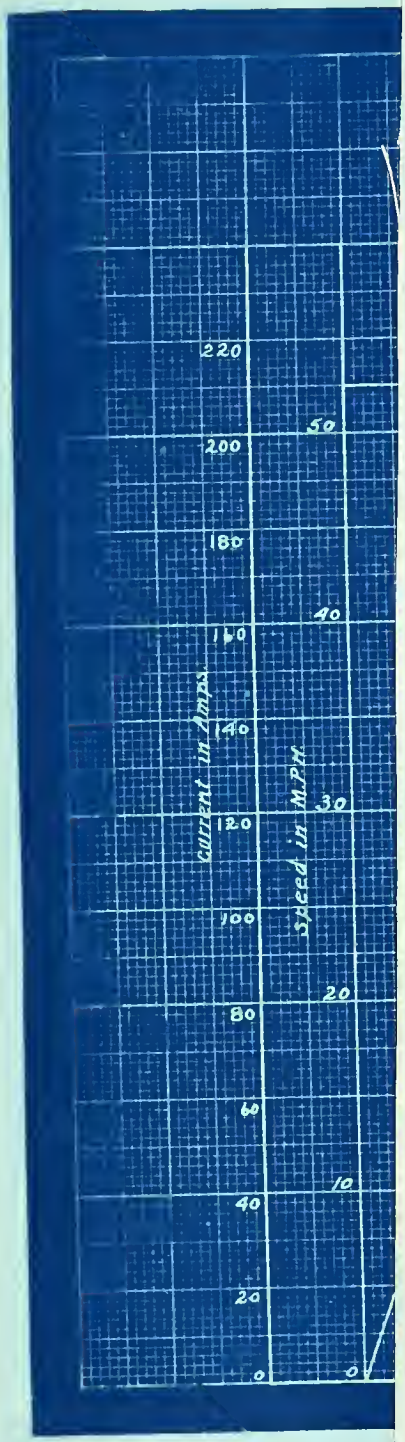
LIBRARY


200
160
120
80
40
50
40
30
20
10
Current - Amperes
Speed - M.P.H.
Speed
Current
0
20
40
60
80
100
120
140
Time - Seconds

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY



C.R.I. & P. RY. MOTOR #4

SPEED-TIME CURVE & TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR, 2 TRAILERS } 18.75 TONS/MOTOR.

α = 1.4 MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	23.8	23.6	23
WT. HRS./TON Mi.	86.6	72.5	64
$\sqrt{\text{MEAN } I^2}$	89.5	84.6	82

S.O.S.

ARMOUR
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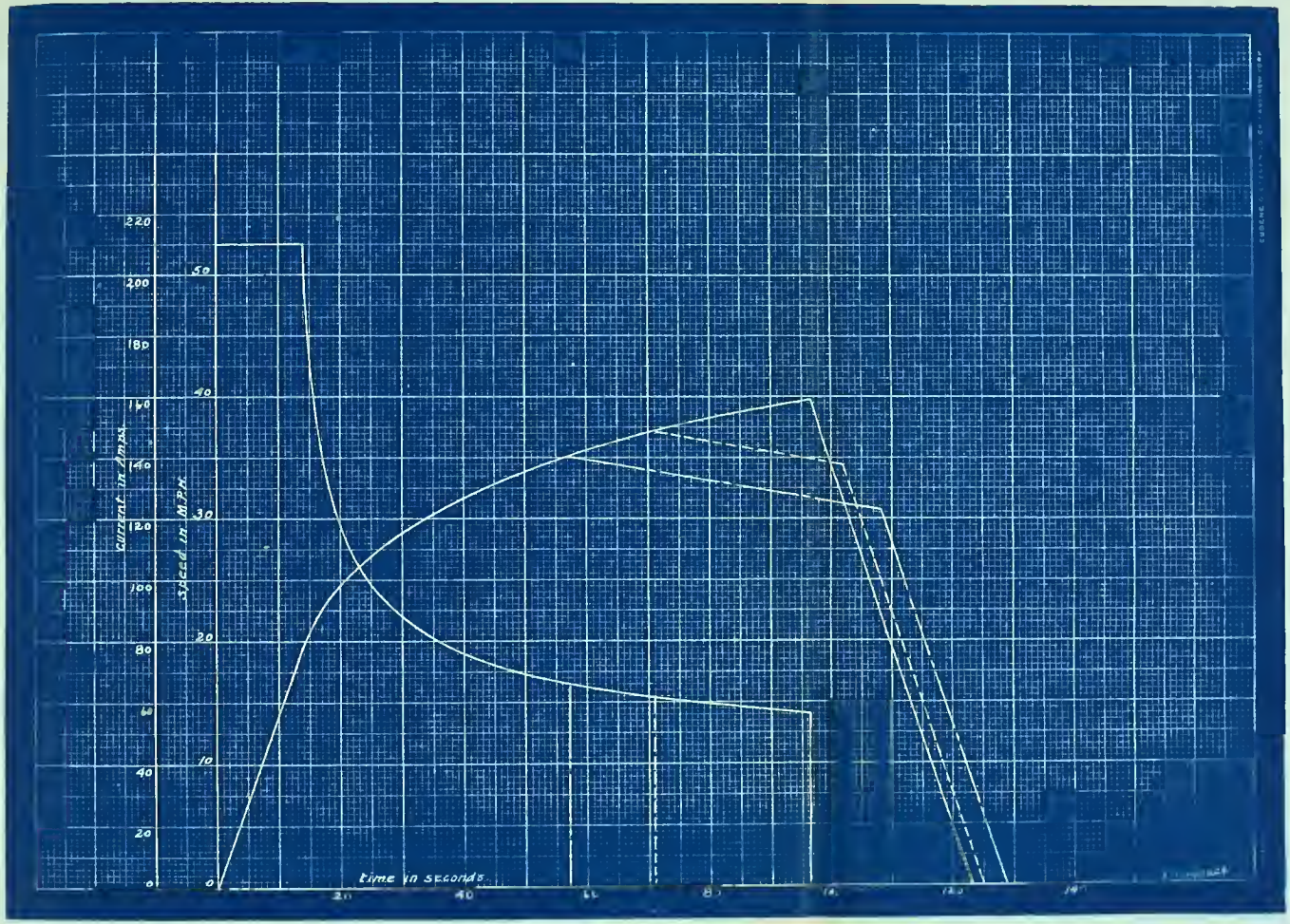
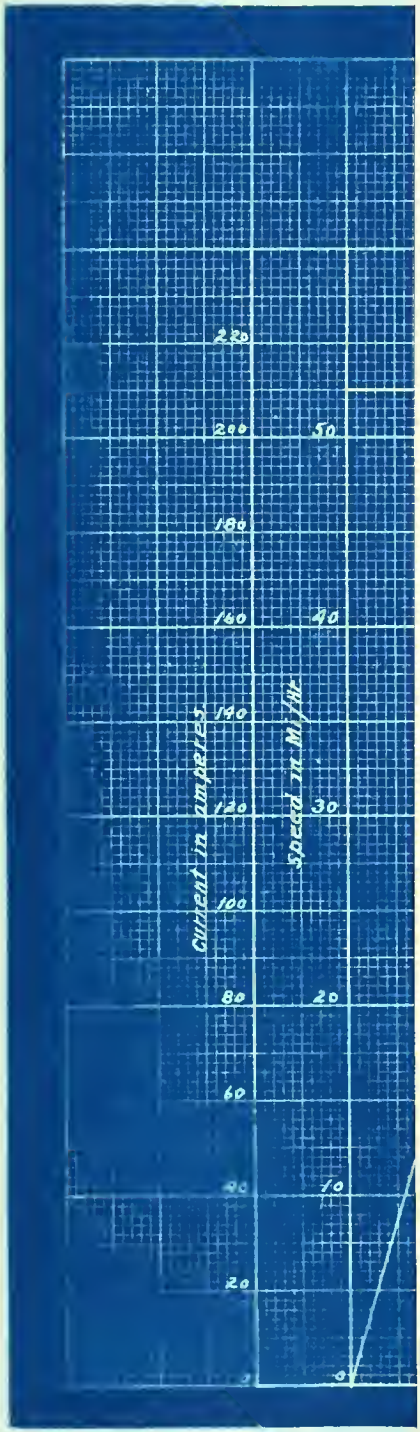
LIBRARY


220
200
180
160
140
120
100
80
60
40
20
0
Current in Amps.
50
40
30
20
10
0
Speed in M.P.H.
20
40
60
80
100
120
140
time in seconds

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.



C.R.I.&P. RY. MOTOR 4

SPEED-TIME CURVE ✦ TYPICAL RUN.

4 CAR TRAIN {2 MOTOR, 2 TRAILERS} 18.75 TONS/MOTOR.

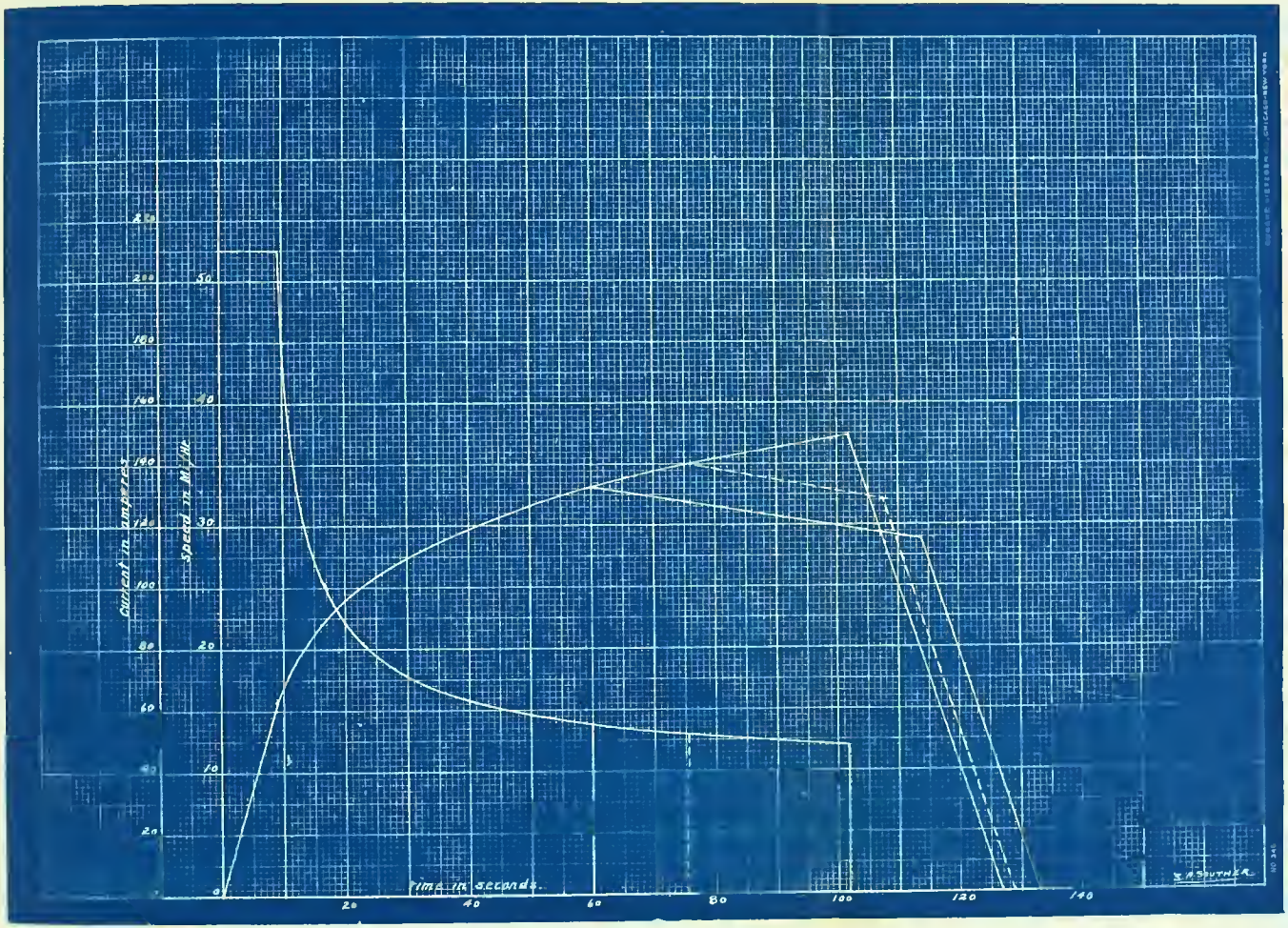
α = 1.7 MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

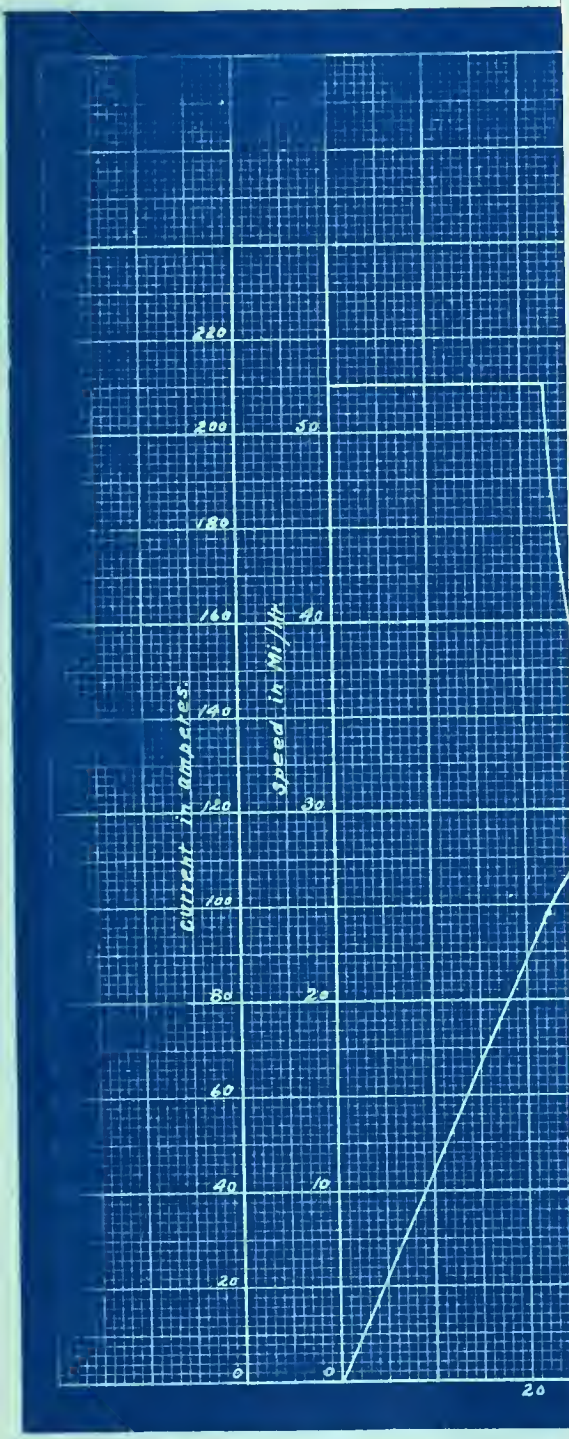
COASTING	0 %	25 %	40 %
SCHED. SPEED	23.3	23	22.4
WT. HRS./TON MI.	73.2	63.3	55.4
$\sqrt{\text{MEAN } I^2}$	76.7	73.5	70.2

S.A.E.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.


Current in amperes
Speed in M.P.H.
Time in seconds.
0
20
40
60
80
100
120
140
200
180
160
120
100
60
40
30
20
10

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.



C.R.I.&P. RY. MOTOR # 1

SPEED-TIME CURVE + TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

α = 1½ MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	24.4	24	23.4
WT. HRS./TON Mi.	1023	86.1	77.
$\sqrt{\text{MEAN } I^2}$	109	101.5	98

S.A.S.

ARMOUR
INSTITUTE OF TECHNOLOGY
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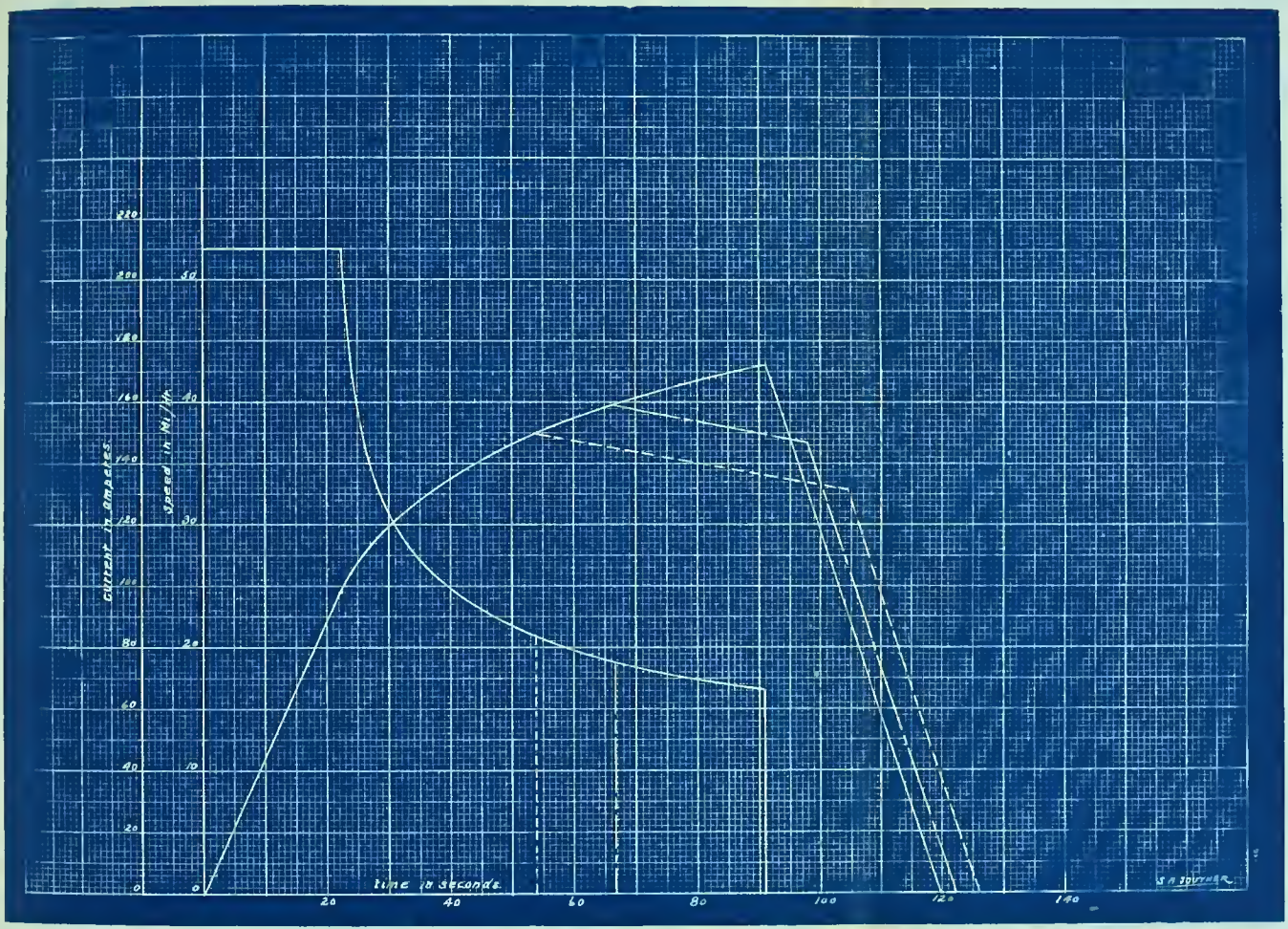
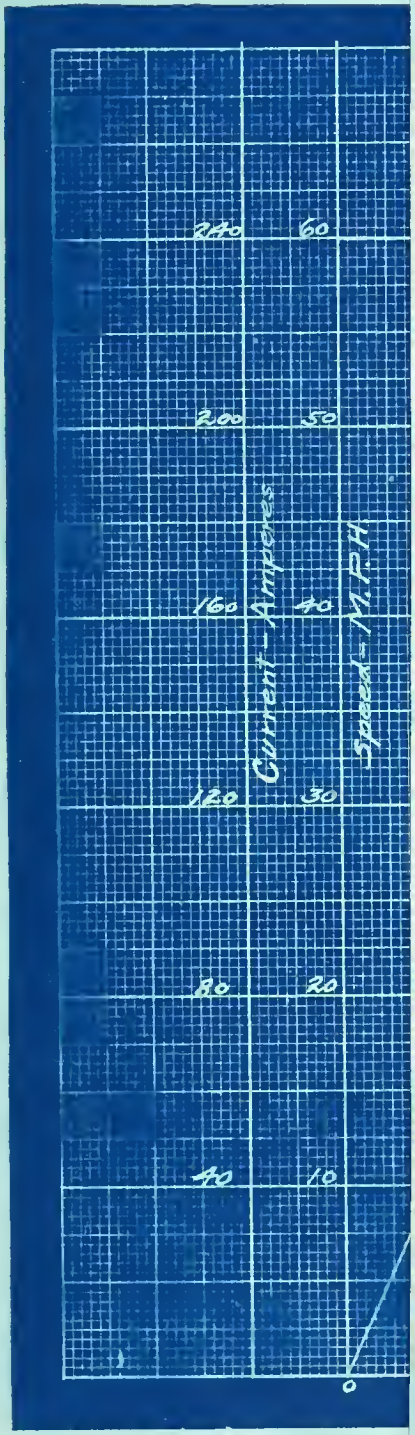

Current in Amperes
Speed in Mi./hr.
Time in Seconds
S.A. Sumner

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.



C.R.I.+P. RY. MOTOR #5

SPEED-TIME CURVE * TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

α = 1.1 MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	26.6	25.2	24.4
WT. HRS./TON Mi.	113.9	101	89
$\sqrt{\text{MEAN } I^2}$	132.3	176.3	119.8

ARMOUR
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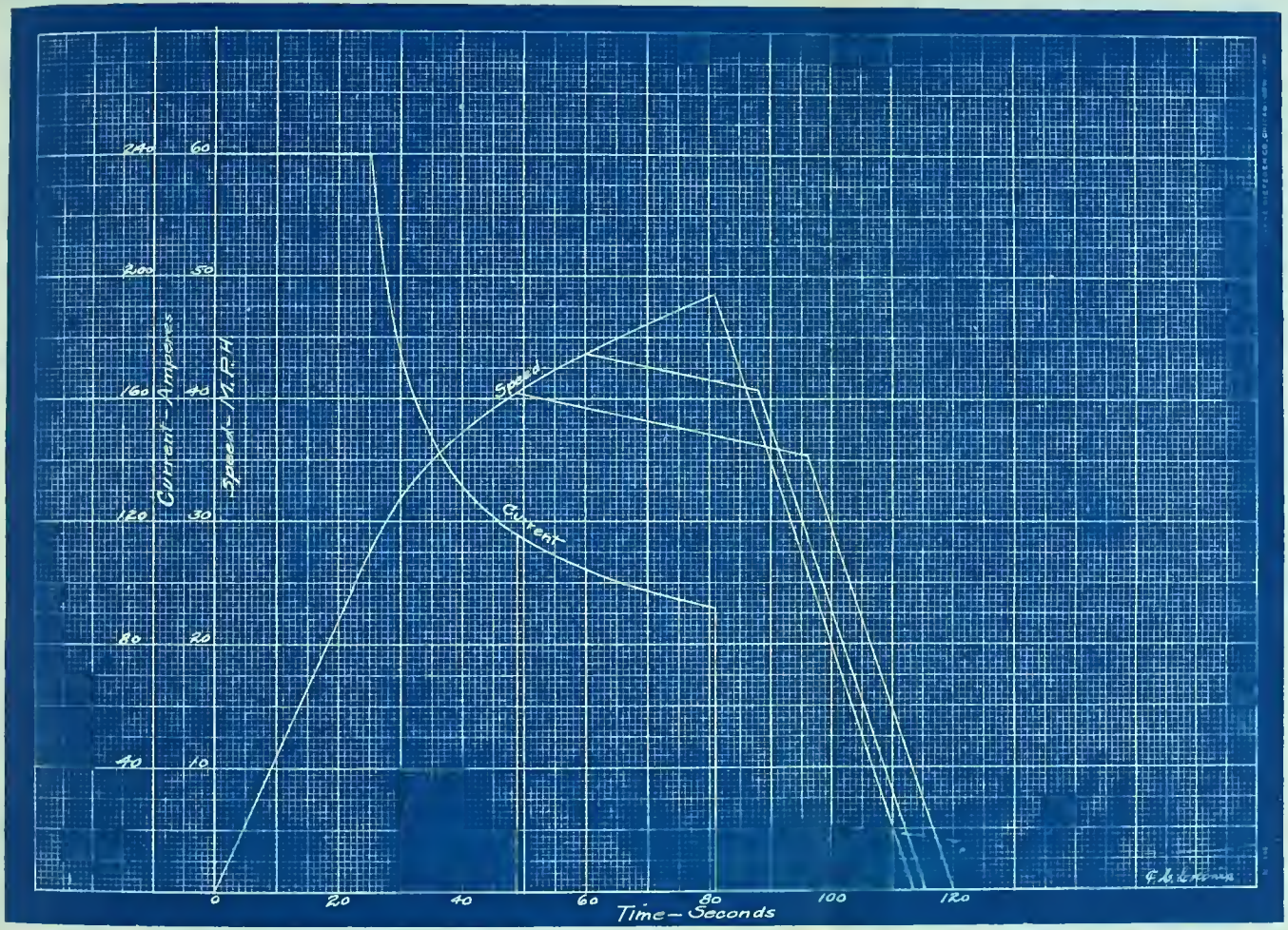
Current - Amperes
Speed M.P.H
240
60
200
50
160
40
120
30
80
20
40
10
Speed
Current
0
20
40
60
80
100
120
Time – Seconds

ARMOUR
INSTITUTE OF TECHNOLOGY
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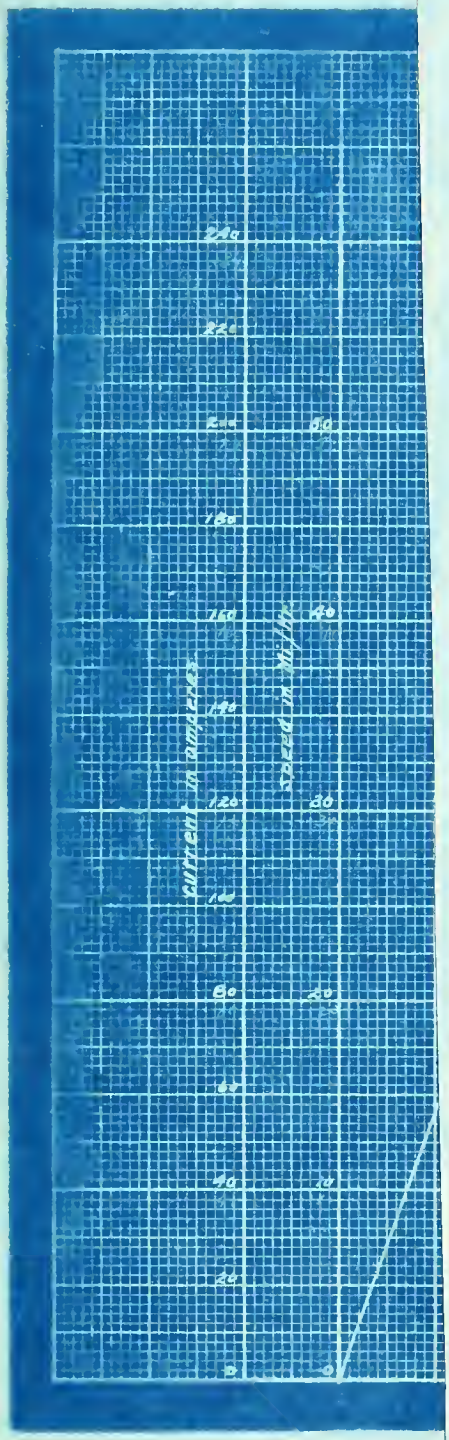

C.R.I.&P. RY. MOTOR #

SPEED-TIME CURVE & TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

$\alpha = 1\frac{1}{4}$ MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	25.4	25	24.4
WT. HRS./TON MI.	100	84.1	74
$\sqrt{\text{MEAN } I^2}$	112	104	102

ARMOUR
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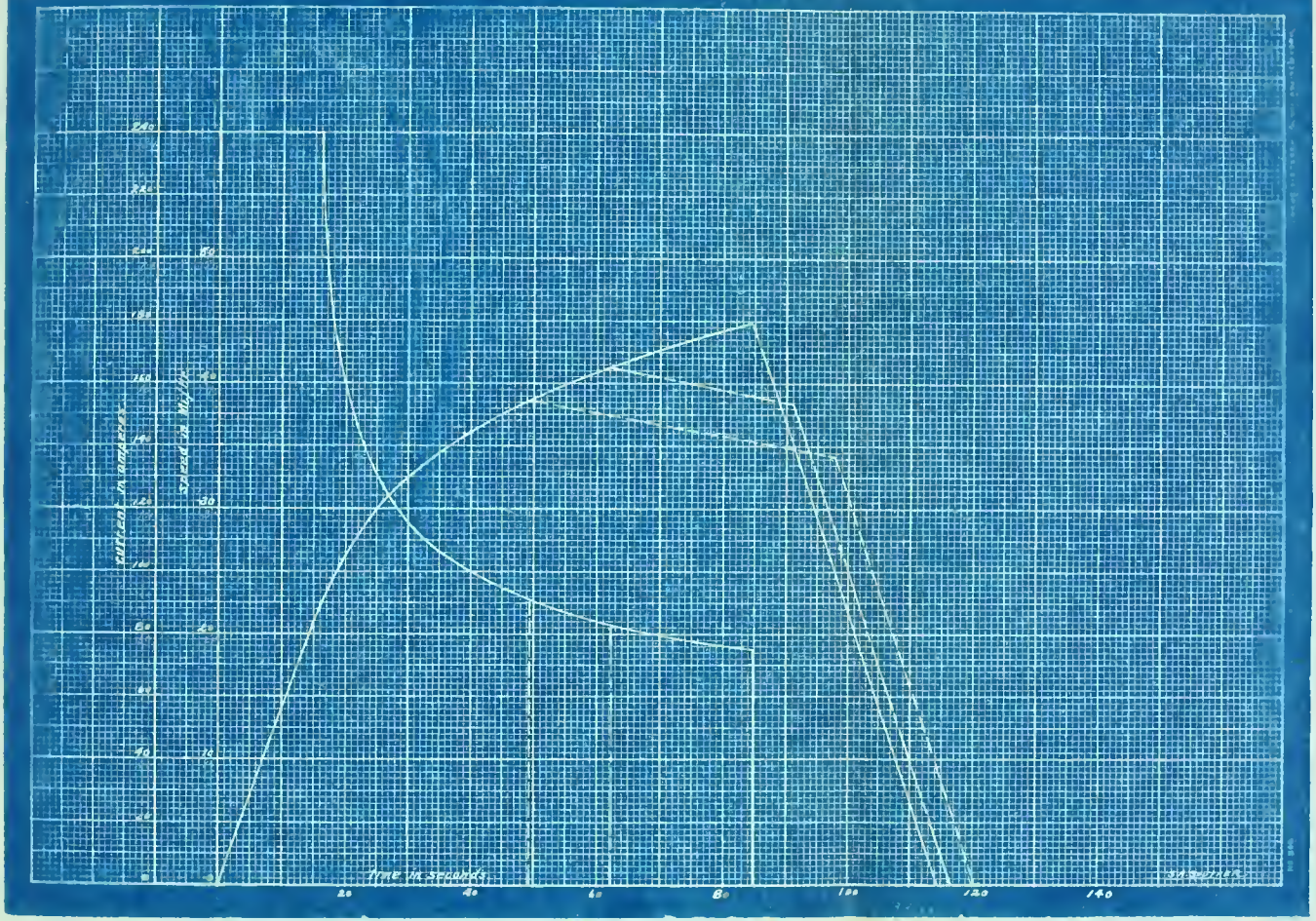
VELOCITY IN MILES PER HOUR
VELOCITY IN FEET PER SECOND
TIME IN SECONDS
20
40
60
80
100
120
140

ARMOUR
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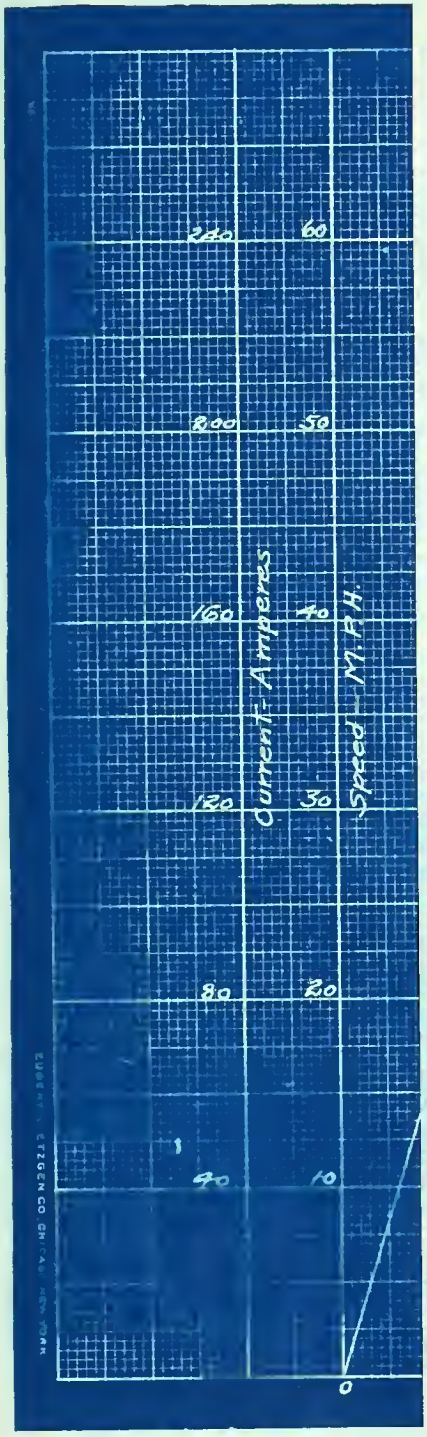


C.R.I.&P. RY. MOTOR # 5

SPEED-TIME CURVE & TYPICAL RUN.

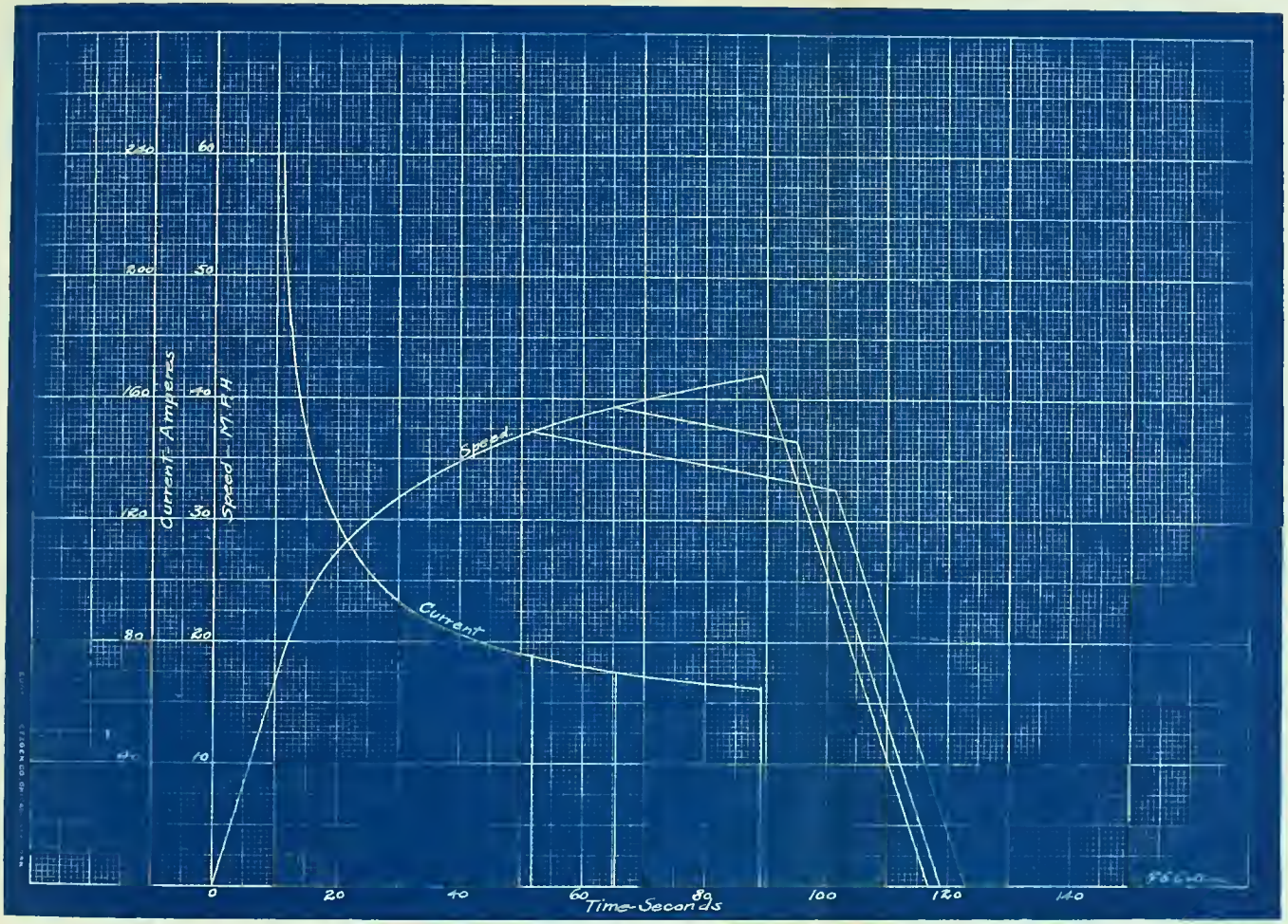
4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

α = 1.7 MI./HR./SEC. B.R. = 1.5 MI/HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	24.9	24.6	23.9
WT. HRS./TON Mi.	68.5	73.9	64.5
$\sqrt{\text{MEAN } I^2}$	94	92.3	88.5

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.


240
200
160
120
80
40
Current Amperes
60
50
40
30
20
10
Speed - M.P.H
Speed
Current
0
20
40
60
80
100
120
140
Time-Seconds

ARMOUR
INSTITUTE OF TECHNOLOGY
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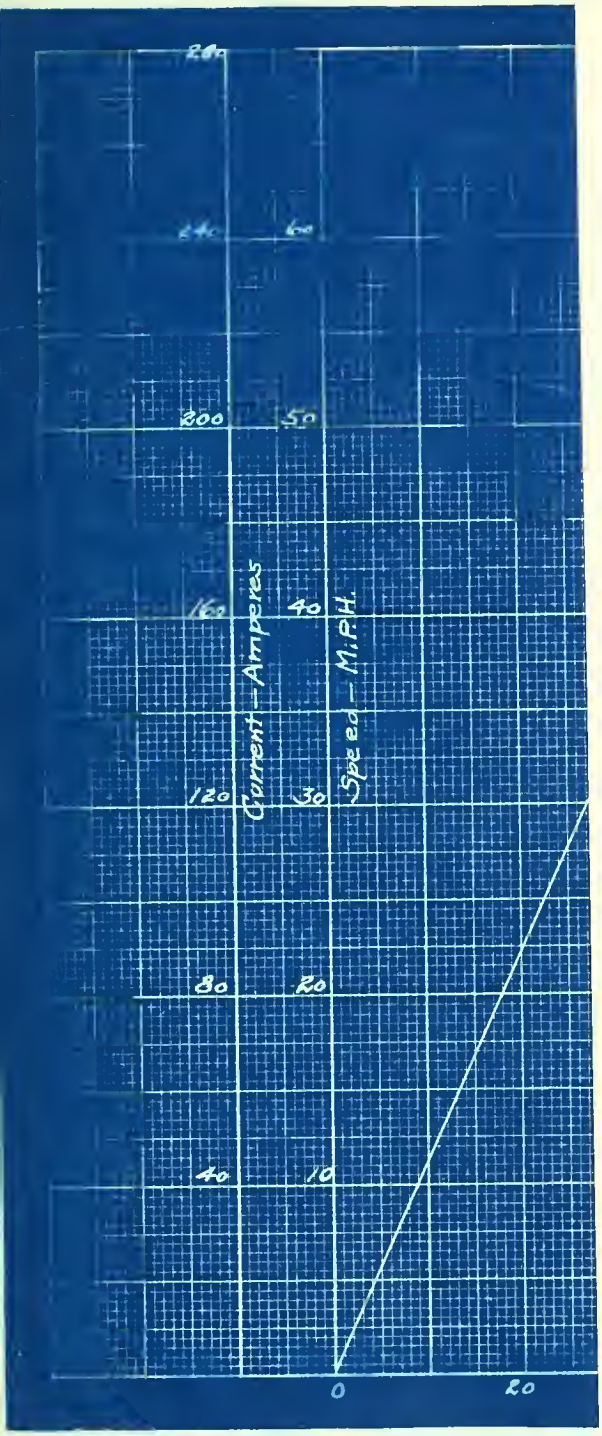

C.R.I.+P. RY. MOTOR #2

SPEED-TIME CURVE + TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

α = 1.1 MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	26.2	25.7	24.8
WT. HRS./TON Mi.	143	120	104.6
$\sqrt{\text{MEAN } I^2}$	161	152	142

S.A.S.

ARMOUR
INSTITUTE OF TECHNOLOGY
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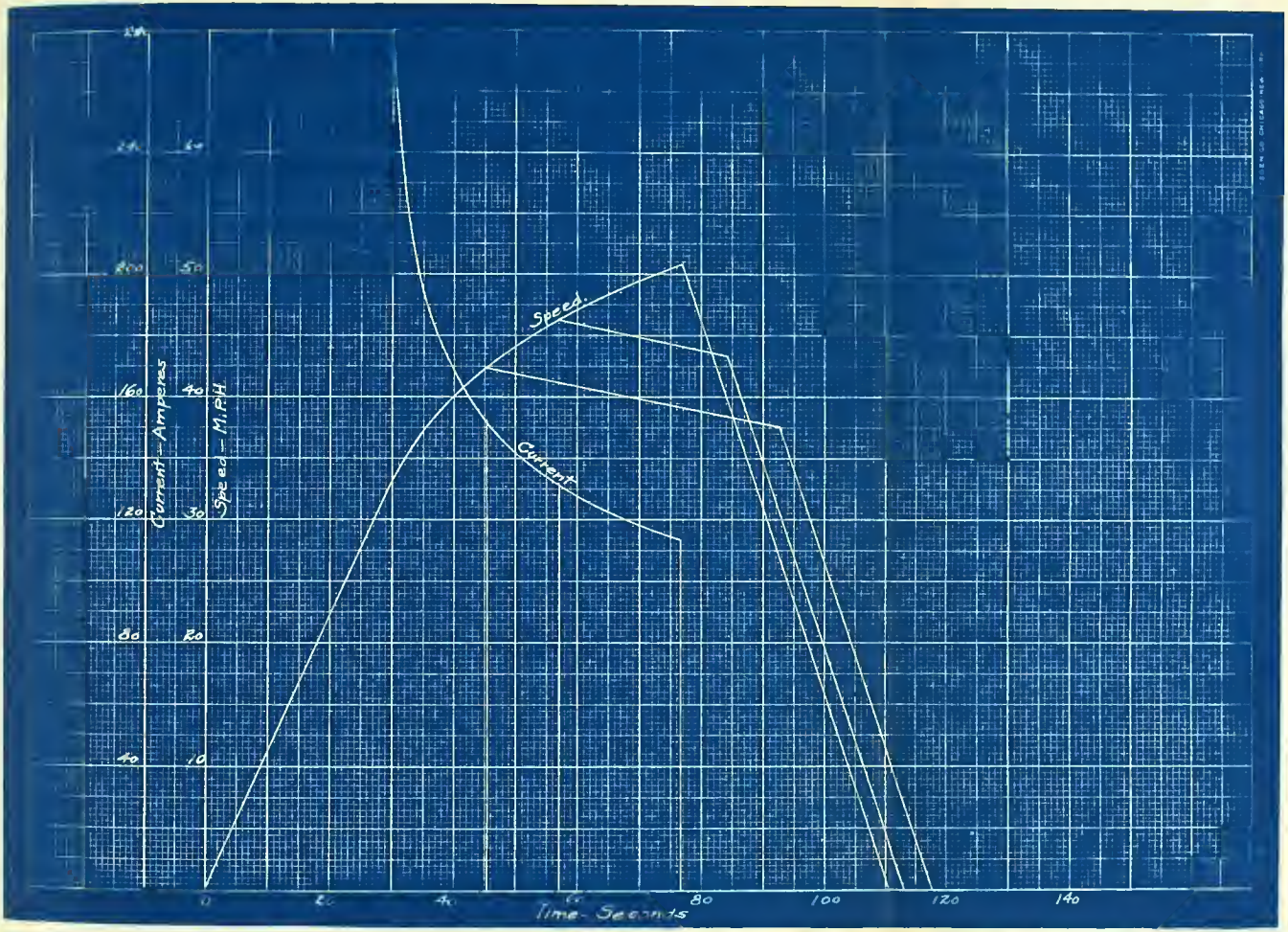
Speed.
Current
Current – Amperes
Speed – M.P.H.
Time – Seconds
0
20
40
60
80
100
120
140
160
200
240
280
320
360
400
10
20
30
40
50

ARMOUR
INSTITUTE OF TECHNOLOGY
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C.R.I.+P. RY. MOTOR # 6

SPEED-TIME CURVE * TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

α = 1½ MI./HR./SEC. B.R. = 1.5 MI/HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	26.3	25.7	25.2
WT. HRS./TON MI.	117	97.2	86.4
$\sqrt{\text{MEAN } I^2}$	137	124	124

S.A.S.

ARMOUR
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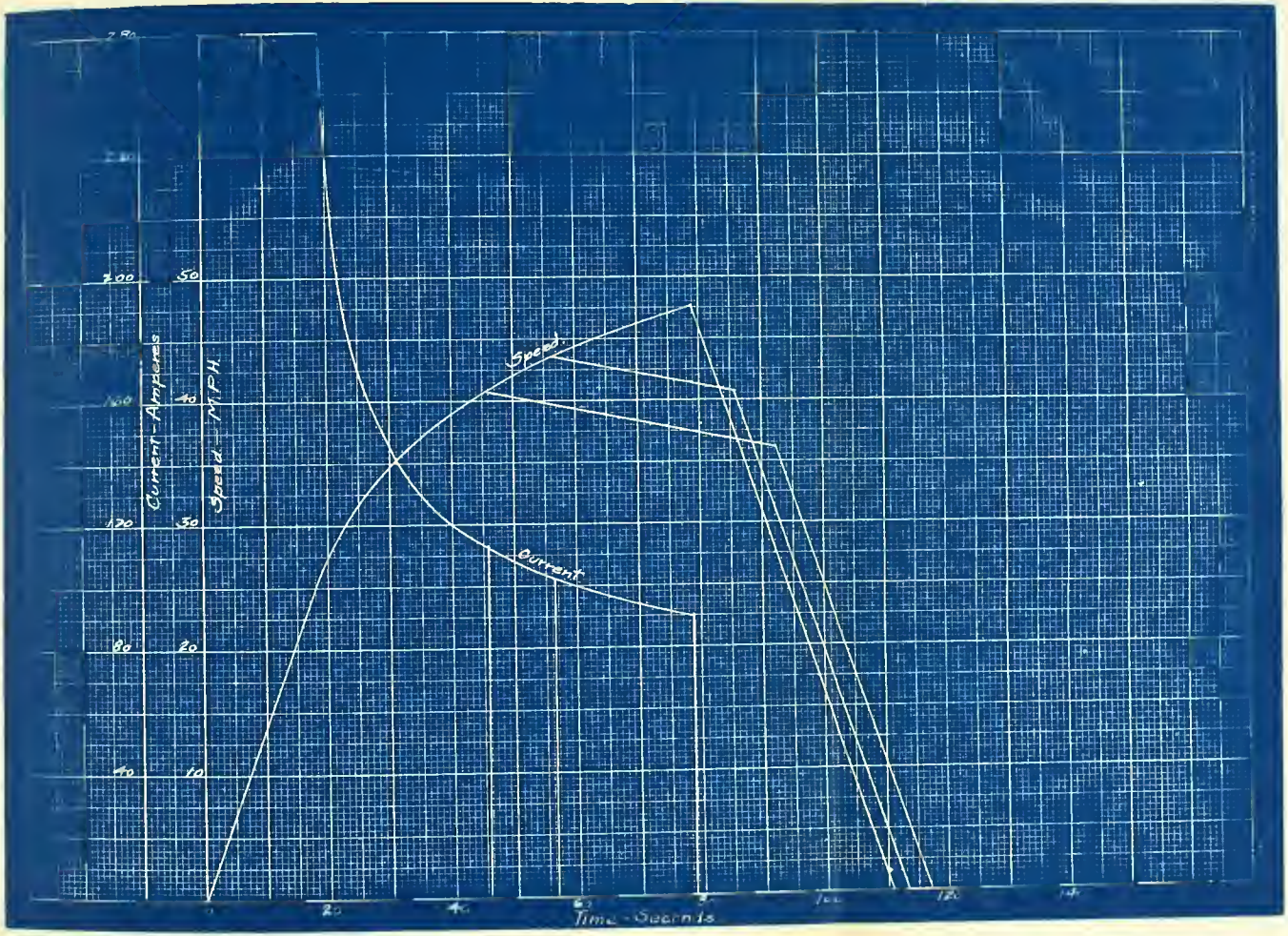
Speed
Current
Current - Amperes
Speed - M.P.H.
Time - Seconds
200
50
100
40
120
30
80
20
40
10
2
4
6
12
14

ARMOUR
INSTITUTE OF TECHNOLOGY
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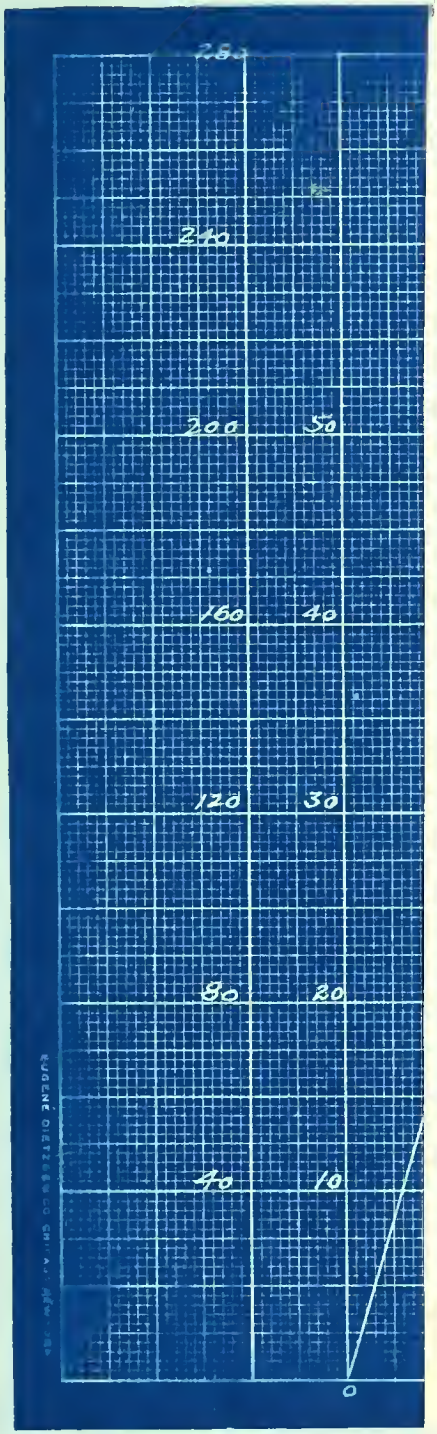


C.R.I.+P. RY. MOTOR #60

SPEED-TIME CURVE ✱ TYPICAL RUN.

4 CAR TRAIN { 2 MOTOR / 2 TRAILERS } 18.75 TONS/MOTOR.

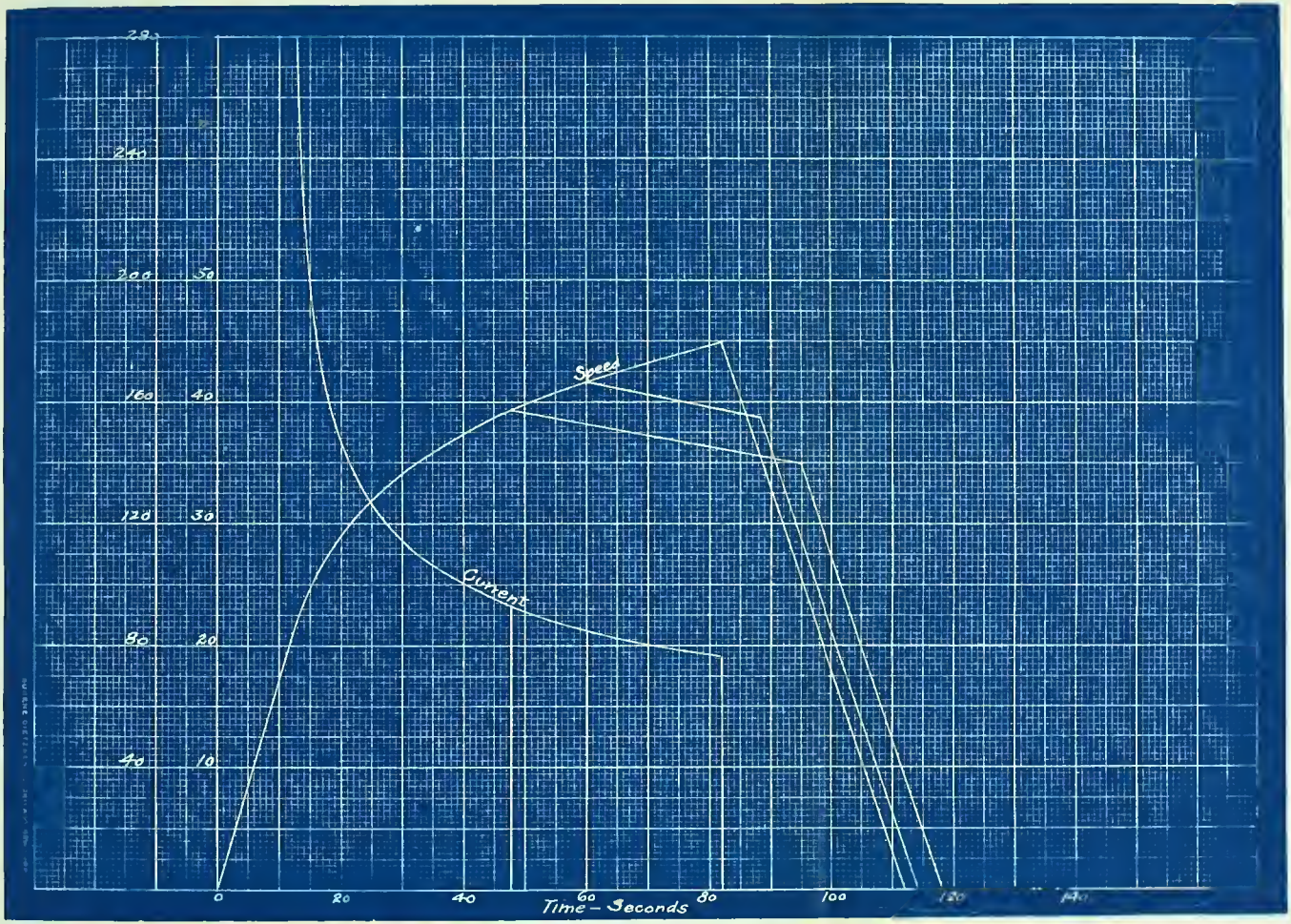
α = 1, 1 MI./HR./SEC. B.R. = 1.5 MI./HR./SEC.

36" WHEELS 600 VOLTS 20 SEC. STOPS.

COASTING	0 %	25 %	40 %
SCHED. SPEED	26	25.5	24.8
WT. HRS./TON MI.	101.8	87.6	75.1
$\sqrt{\text{MEAN } I^2}$	118	112.5	108

S.A.S.

ARMOUR
INSTITUTE OF TECHNOLOGY
LIBRARY.


280
240
200
160
120
80
40
50
40
30
20
10
Speed
Current
0
20
40
60
80
100
120
140
Time – Seconds

ARMOUR
INSTITUTE OF TECHNOLOGY
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	TIME OF RUN. (SECONDS.)	MAX. SPEED.
MOTOR # 1.		
0% COASTING	124.6	39.9
25% "	129.2	36.6
40% "	133.9	34.5
MOTOR # 2.		
0% COASTING	130.5	37.3
25% "	133.	35.
40% "	137.5	33.
MOTOR # 3.		
0% COASTING	122.5	41.3
25% "	124.9	38.4
40% "	129.	36.
MOTOR # 4.		
0% COASTING	119.9	43.
25% "	122.1	39.8
40% "	126.	37.5
MOTOR # 5.		
0% COASTING	113.7	48.6
25% "	115.6	43.7
40% "	120	46.5
MOTOR # 6.		
0% COASTING	110.4	50.5
25% "	113.	46.
40% "	117.6	42.2

ARMOUR
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	TIME OF RUN. (seconds.)	MAX. SPEED.	SCHEDULE SPEED. m.p.h.	WATT HRS. PER TON MI.	√MEAN I² (Amperes)	TIME OF RUN. (seconds.)	MAX. SPEED.	SCHEDULE SPEED. (m.p.h.)	WATT HRS. PER TON MI.	√MEAN I² (Amperes)	TIME OF RUN. (seconds.)	MAX. SPEED.	SCHEDULE SPEED. (m.p.h.)	WATT HRS. PER TON MI.	√MEAN I² (Amperes)
	$\alpha = 1.1$					$\alpha = 1.4$					$\alpha = 1.7$				
MOTOR #1.															
0% COASTING	121.6	39.9	23.35	82.5	92.7	129.6	37.	22.9	73.2	67.5	135.6	33.7	21.97	63.6	59.2
25% "	129.2	36.6	22.9	69.4	75.7	131.3	34.6	22.6	58.9	65.1	137.6	32.	21.7	53.3	56.9
40% "	133.9	34.5	22.3	62.	73.5	136.2	32.8	21.4	51.7	62.1	141.9	30.8	21.1	46.1	53.3
MOTOR #2.															
0% COASTING	130.5	37.3	22.7	75.	70.4	136.	34.5	22.	65.	58.8	143.1	31.5	20.95	60	50.
25% "	133.	35.	22.3	62.3	66.6	138.5	32.4	21.55	54.	55.4	145.	30.1	20.7	48.5	47.6
40% "	137.5	33.	21.7	54.9	63.4	144	31.	20.35	47.6	52.	150	29.	20.1	43.3	45.2
MOTOR #3.															
0% COASTING	122.5	41.3	24.	91.8	92.6	125.1	38.5	23.45	76.4	74.9	131.3	35.	22.6	69.	66.
25% "	124.9	38.4	23.53	77.5	87.8	129	36.	23.0	64.4	71.6	133.	33.6	22.35	58.8	63.5
40% "	129.	36.	22.95	68.8	84.	133	34.	22.35	57.2	69.5	138.	32.	21.6	51.0	60.2
MOTOR #4.															
0% COASTING	119.9	43.	24.45	102.3	107.	123.2	39.8	23.55	86.6	89.5	126.9	37.4	23.3	75.2	76.7
25% "	122.1	39.8	24.0	86.1	101.5	125.	37.1	23.6	72.5	84.6	128.5	35.	23.	63.3	73.5
40% "	126.	37.5	23.4	77.0	98.	128.9	35.	22.95	64.1	82.0	132.5	33.1	22.4	55.4	70.2
MOTOR #5.															
0% COASTING	113.7	48.6	25.65	113.7	132.3	114.4	45.	25.4	100.	112	117.	41.75	24.9	88.5	97.
25% "	115.6	43.7	25.2	101.	126.3	116.5	41.2	25.04	84.1	106.8	119.	39.2	24.65	73.9	92.3
40% "	120	41.5	24.42	89.	119.8	120.2	38.6	24.4	74.	102.	123.1	37.1	23.9	64.5	88.5
MOTOR #6.															
0% COASTING	110.4	50.5	26.2	143.	161.	110	47.5	26.3	117	137	112	44.75	26.	101.8	118.
25% "	113.	46.	25.75	120.	152.	113	43.5	25.7	97.2	129	114	41.5	25.5	87.6	112.5
40% "	117.6	42.2	24.8	104.6	142.	116	40.7	25.2	86.4	124	118	39.2	24.85	75.1	108.

ARMOUR
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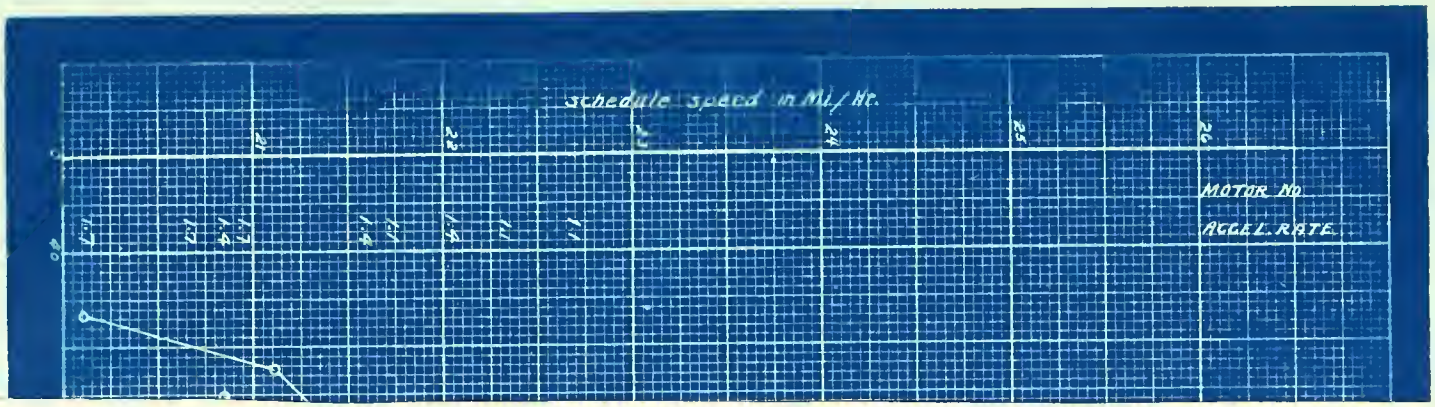
Schedule Speed in Mi./Hr.
20
22
24
25
26
MOTOR NO.
ACCEL. RATE.

ARMOUR
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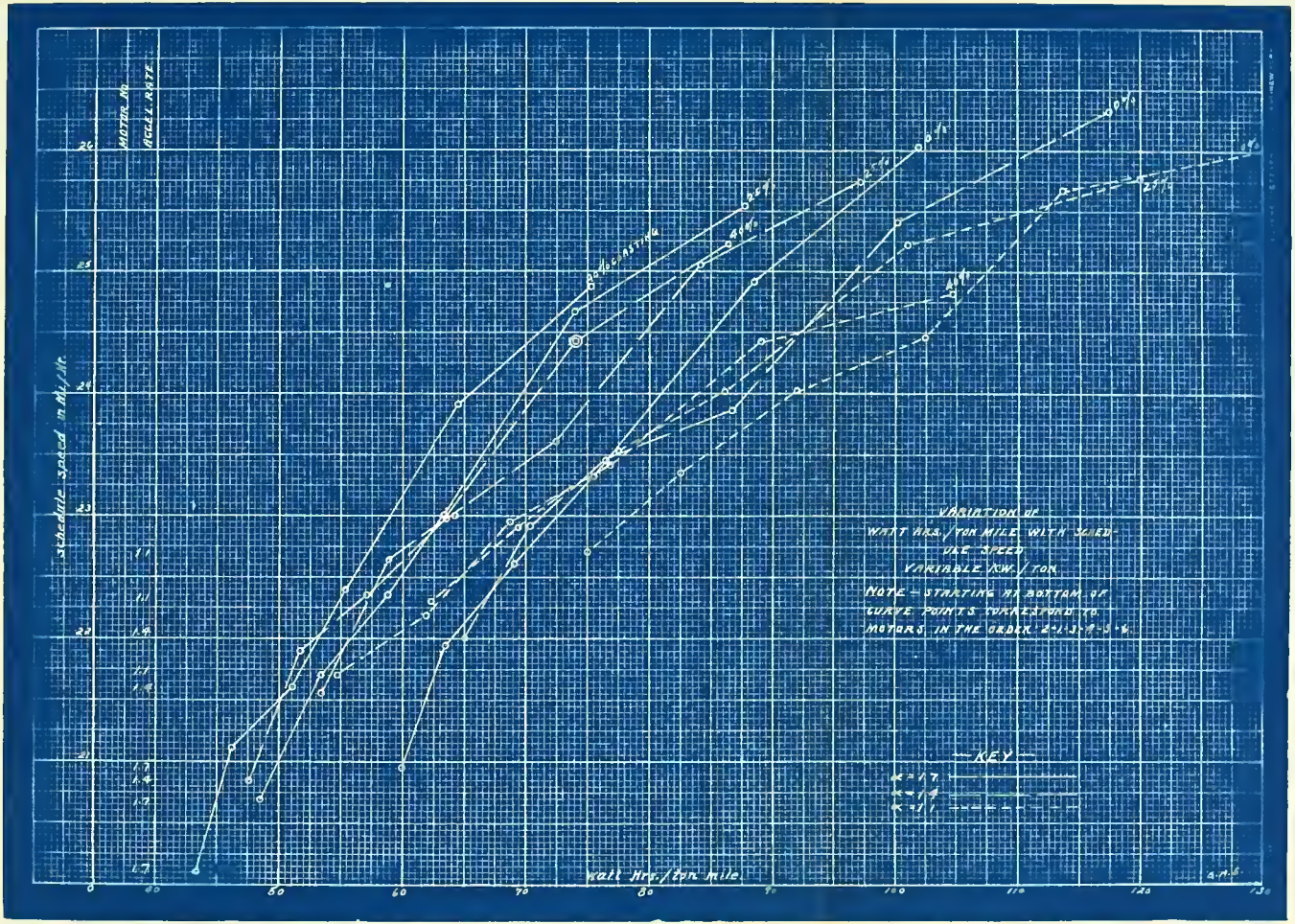
Schedule Speed in Mi./Hr.
Watt Hrs./Ton Mile
MOTOR NO
ACCEL. RATE
VARIATION OF
WATT HRS./TON MILE WITH SCHED.
AVE. SPEED
VARIABLE KW./TON
NOTE - STARTING AT BOTTOM OF
CURVE POINTS TOWARDS TOP.
MOTORS IN THE ORDER 2-1-3-4-5-6
KEY
A.R.E.

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MOTOR NO
schedule speed - in Mi/Hr
40

ARMOUR
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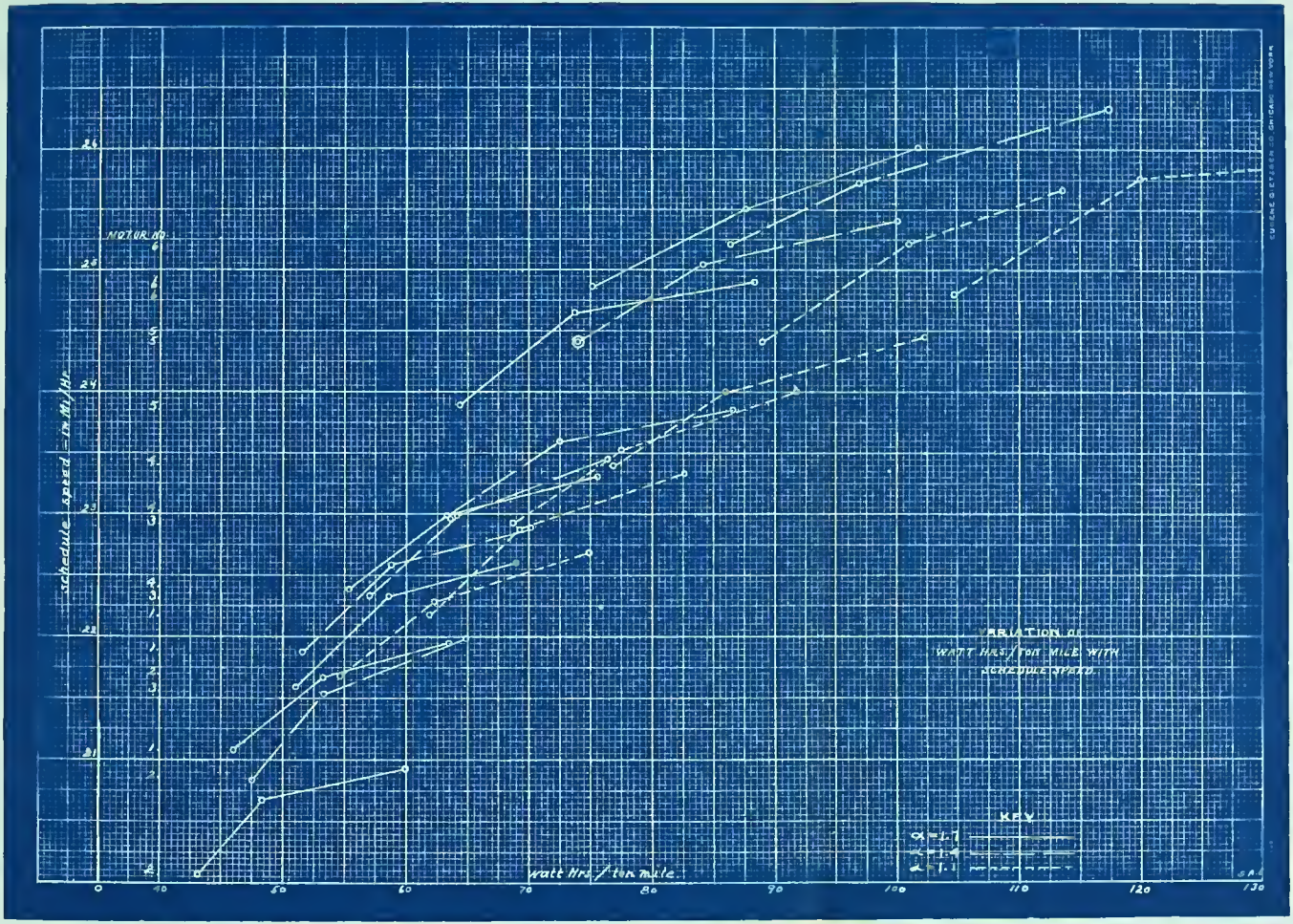
MOTOR 80
Schedule speed - in M./Hr.
Watt Hrs. / ton mile.
0
40
50
60
70
80
90
100
110
120
130
VARIATION OF
WATT HRS. / TON MILE WITH
SCHEDULE SPEED.
KEY
a = 1.7
a = 1.4
a = 1.1

ARMOUR
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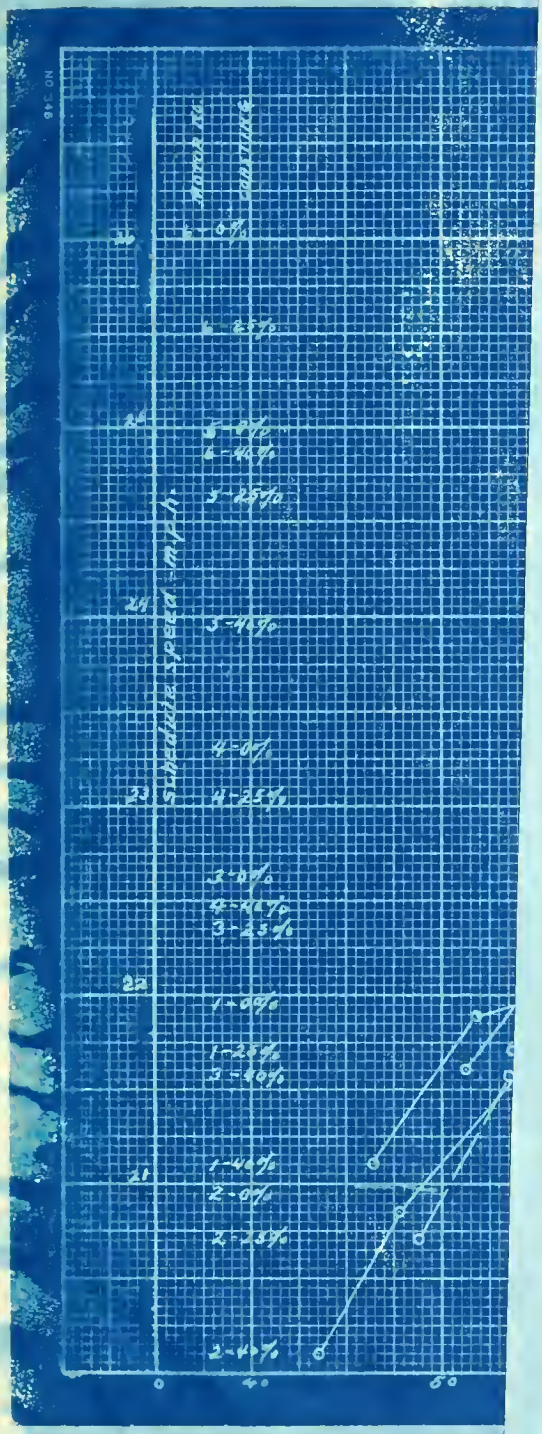
Synthetic speech - mixed
Amount of
5 - 0%
4 - 44%
3 - 25%
3 - 41%
4 - 0%
4 - 25%
3 - 0%
4 - 21%
3 - 25%
1 - 0%
1 - 25%
3 - 40%
1 - 44%
2 - 0%
2 - 33%
2 - 42%
0
40
60

ARMOUR
INSTITUTE OF TECHNOLOGY
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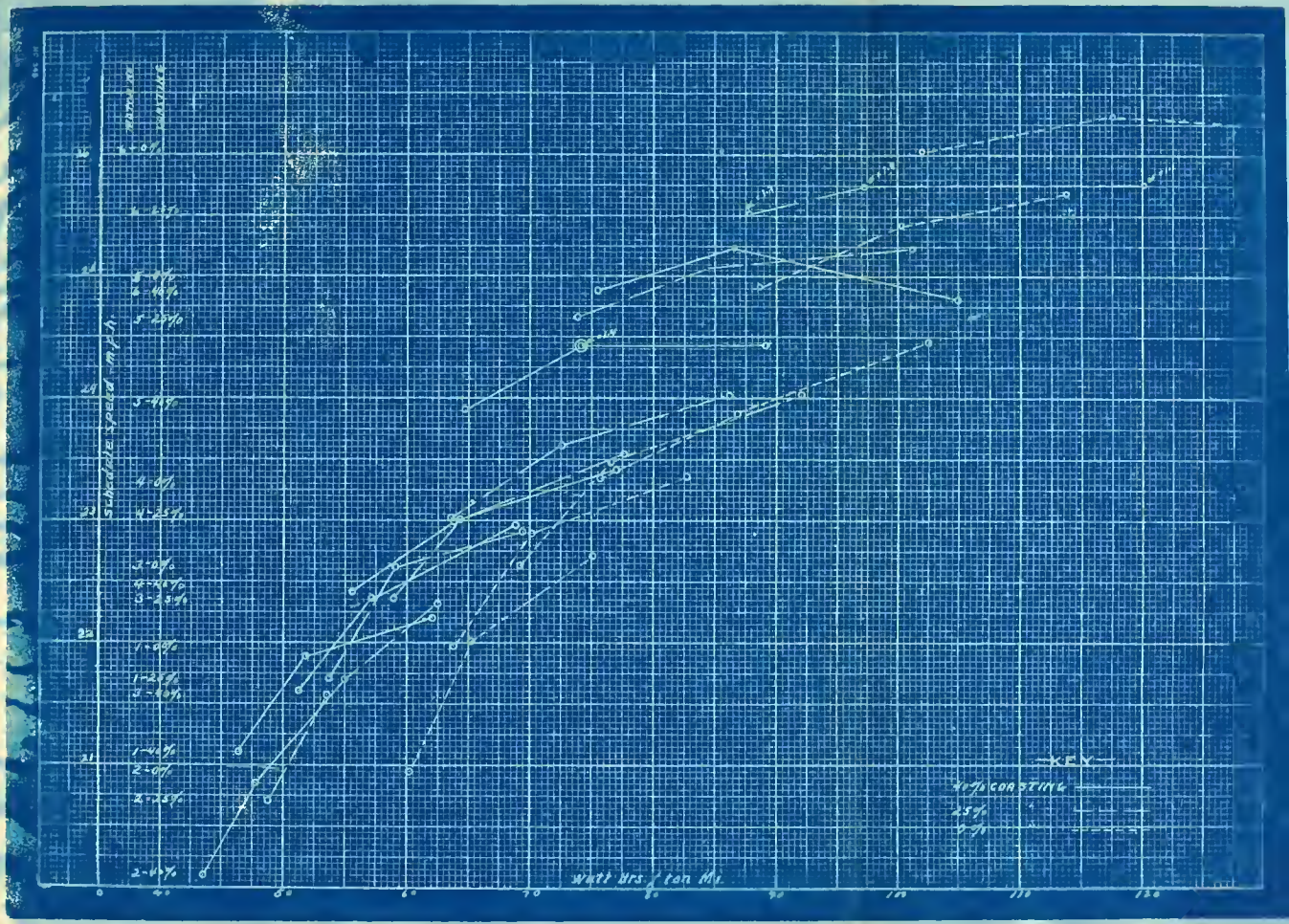
Schedule Speed M.P.H.
Watt Hrs / ton Mi.
KEY
1% Constant
.5%
2%

ARMOUR
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120
110
100
90
MEAN
80
70
60
50
40
0

ARMOUR
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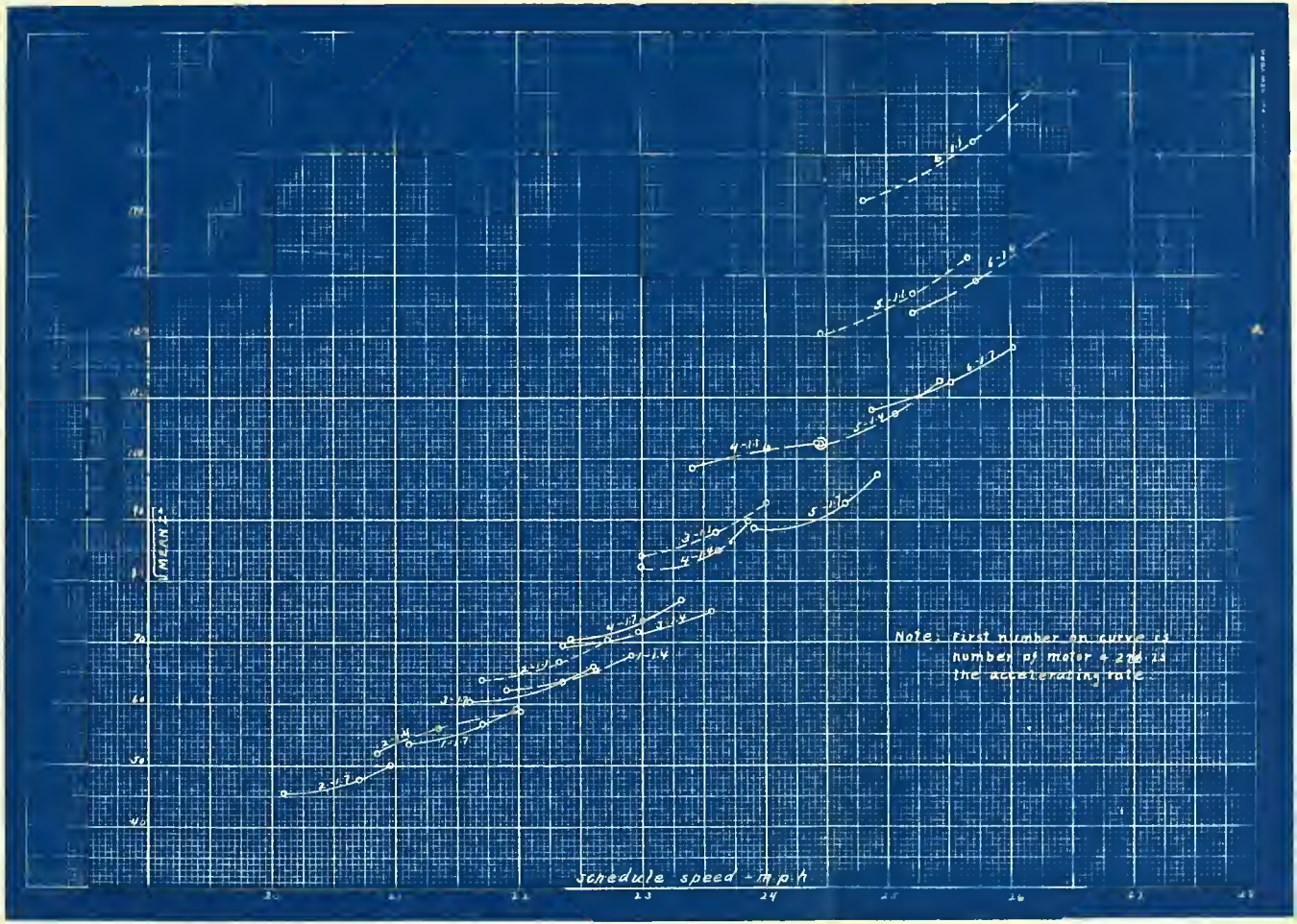
Schedule speed - m.p.h.
Note: first number on curve is number of motor + 2nd is the accelerating rate.

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